TRANSACTIONS

OF THE

SEISMOLOGICAL SOCIETY OF JAPAN.

VOL. I.—PARTS I & II.

APRIL—JUNE, 1880.

CONTENTS.

PART I.

PART II.

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PART I.

PART II.

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NOTE.

Owing to arrangements for printing not having been entered into until some time after the Society had been established, some irregularity in the order in which the papers appear has occurred. The order in which the papers appear in the table of contents is the order in which they were read.

The discussion on pages 35, 36, 37 ought to appear after page 43.

TRANSACTIONS OF THE SEISMOLOGICAL SOCIETY OF JAPAN.

ON Monday the 26th April 1880 the members of the society held a general meeting in the lecture hall of the Kaisei Gakko, the business being the election of a president, in consequence of His Excellency Yamao Yozo having declined, through press of business, to accept the presidency of the society; the reading of a paper on seismic science by Professor John Milne, and a description of a new seismograph invented by Professor J. A. Ewing.

The attendance was very good.

The vice-president of the society, Professor Milne, took the chair and called the meeting to order by announcing that the secretary, Professor Chaplin, would read the minutes of the previous meeting.

The minutes having been read and confirmed, the secretary reported that the committee had adopted the following regulations for conducting general business.

1.—Reading of minutes of last meeting.
2.—Reports from committee and officers.
3.—Reports from other committees.
4.—Papers.
5.—Miscellaneous communications.
6.—Miscellaneous business.

The following letter from His Excellency Yamao Yozo was then read:—

Public Works Department,
Tokio, 27th March, 1880.

W. S. Chaplin. Esq.
Secretary, Seismological Society.

Sir:—I have the honour to acknowledge the receipt of your letter of the 15th instant in which you notify me that I was at the

first meeting of the Seismological Society elected to the office of president.

I very much regret to have to inform you in reply that the vast amount of official duties with which I am continually pressed, prevent me from availing myself of the pleasure of accepting that office.

Requesting you to convey to your colleagues my warm thanks for their conferring upon me this honourable post, but one which I am forced to decline by the circumstances above mentioned,

I have the honour to be, Sir,

Your obedient servant,

YAMAO YOZO.

The chairman remarked that many now assembled were present when his Excellency was elected president of the society, and he felt sure that they would regret very sincerely the inability of the minister to accept the position of president. As a new election was now rendered necessary he (the chairman) thought it would be as well to elect a gentleman who was a member of the society.

Mr. Netto proposed Professor John Milne as president.

Mr. Marshall was in favour of a Japanese gentleman for president, as in that case the society would have the benefit of the experience of a gentleman more acquainted with the different parts of the country than a foreign president would probably be, and one who would be able to get information from remote districts which could not be got otherwise. And the gentleman he (Mr. Marshall) thought most suitable to fill the position of president was Mr. Hattori, who not only understood English, but was connected with the Kaisei Gakko and took a keen interest in seismic science. He therefore had much pleasure in proposing Mr. Hattori for the presidency.

Mr. Milne intimated that he already occupied the position of vice-president, and if the meeting insisted on electing him president that would necessitate a further election of a vice-president. He did not think they could do better than elect Mr. Hattori.

The ballot was then taken and resulted in the election of Mr. Hattori.

The following paper was then read by the chairman :—

SEISMIC SCIENCE IN JAPAN.

GENTLEMEN :—To-day I have the honour of addressing a society whose main object is to collect and systematise facts which are in any way connected with earthquakes and volcanos. It is intended that the society's chief work shall be to gather together and correlate phenomena which emanate from the interior of the earth; and whereas nearly all the learned societies, of which there are so many in European countries, chiefly study that which is on the exterior of our planet the objects of this society are decidedly peculiar. Where the work of a Seismological Society commences and where it ends, would, like the work of many other scientific societies, be difficult to define. In its narrowest sense it would be confined to the description of shakings which from time to time occur upon the surface of the earth's crust. In its broader signification, in its treatment of the origin of earthquakes and their consequences, we might compare its vast extent to the exaggerated representation of the action of a pebble which, dropped into the ocean, we can conceive as being the cause of more or less effect throughout the world. To the geologist a knowledge of earthquakes and volcanos is of primary importance, whilst to the physicist, the meteorologist, the astronomer, the mathematician, the engineer, and, I might add, the physician, the naturalist, the historian, and the student of national character, the study of these phenomena and their co-ordination with the phenomena of other sciences, affords a field for research from which much has yet to be gathered in.

The task is great, and one of the first problems which come before us is to determine how it is to be accomplished. No doubt the same end may be attained by different methods, but it behoves us always to strive after that which is the best. At the outset it would seem well to obtain first a clear idea of the goal we are endeavouring to reach. Next we might consider the roads it would be necessary to follow to attain it successfully, and finally, we might examine how

far previous workers in seismology have advanced along the paths we desire to follow.

Work of this nature might be likened to that before an artist, who is asked to complete a picture which has already been commenced. This being the case, we will now ask ourselves how such an artist would proceed. If we were to watch him I think we should first see him stepping back whilst endeavouring to form a general idea of the sketch which had to be completed. Having formed this idea, he would next proceed to scrutinize the work of those who had preceded him, and carefully consider how it was likely to harmonise with that which was as yet undrawn. Being satisfied on this point he would next examine the details of the parts which had already been completed and see how far these were in unison with each other. Perhaps, some of these would be perfect, others would require to be renewed, and others to be improved upon.

If the task imposed upon us is at all similar to this, not only must we lay before ourselves the work which has already been done in Japan, but it will be necessary for us to see how far it is in concord with that which has been done in other countries, and picture to ourselves the general results towards which all such labours aim. The scheme proposed is one of descent from generals to particulars; from a goal to be attained to the consideration of the roads which reach it. It is like an argument from theory down to facts. When a savage discovered that by rubbing two sticks together he could make a fire, or when a blacksmith found that by hammering a piece of steel it became so hot that it enabled him to light his pipe, the results arrived at were not attained by a preconceived theory of heat, but from experience, and here facts led up to theory. Although many important generalizations have been arrived at by methods similar to these, we must remember that many of the greatest triumphs of scientific discovery have been reached by methods which are entirely opposite, and instead of facts leading up to theory, theory has led down to facts. It was by following out the theory of gravitation that Adams and Leverrier

discovered Neptune, and by investigation based upon the undulatory theory of light, that Sir William Hamilton discovered conical refraction.

In pursuing the question before us, we might either follow the method of Leverrier and Hamilton, or that of the blacksmith and the savage, and in either case we might attain valuable results. Let us take the former and commencing with the idea of what the picture ought eventually to be, consider the details necessary for its completion.

Now, what is the picture we are required to draw?

Amongst the various objects towards which man aims one of the most laudable is, perhaps, a study of the human race, with a view to discover the various factors which have been at work to bring it to its present condition, and, if possible, to remove the obstacles which bar its future progress.

History tells us of fierce wars, the conquest of provinces, the rise and fall of empires, and generally, of the mutual actions and re-actions of a multitude of nations. In its records we read of a gradual increase in knowledge which has led to dissatisfaction with that not suited to the times, and demands for reformation. How far nature has been instrumental in advancing or retarding this onward march of nations is a theme familiar to us all.

If we wish to investigate this latter division of the scheme which is before us, much may be learnt by a study of those operations which are visibly at work around us. For the remainder, however, we must go to those records which are buried in the rocks or have been sculptured on the hills. By doing this we shall find that in nearly every country, long antecedent to the time of man, vast changes have taken place about which the records of written history tell us little. Climates which now are mild and balmy were once cold and stormy. Continents have risen from the ocean and others have disappeared beneath its waves. Lands, which now are fair with corn fields and softly flowing rivers, were once the scene of violent volcanic activity. What would many of the inhabitants of Britain say if we talked to them of the volcanos of the Hebrides and of Wales, or the

inhabitants of Hungary when they heard a discussion about a volcano at Chemnitz? When they looked upon these huge hummocks clothed with verdure they might doubt our words, but yet to those who have studied these formations the statements sound as true as that the sun rose yesterday. All is change, and to understand the conditions which we see around us at the present we must endeavour to trace their evolution from the past. Should we, for instance, wish to know the reason why the people of Japan or England are as we see them now, we shall find ourselves driven back from history to geology and from geology to the evolution of our globe. One great influence which has acted upon the people of almost every soil has been their geographical position, which gives to them their climate, and aids or debars them in their intercourse with others. The climate of a country, however, largely depends upon its configuration, and its configuration often depends to a great extent upon the nature of its rocks. The hard rocks will stand up to form the mountains, or, projecting out to sea become promontories, whilst the softer rocks will form the plains, or be cut back to form the bays. The mountains will influence the rain fall; the soils will depend upon the underlying geological formations. The industries of a district will depend upon its geology: in the mountains we shall find miners and hunters leading a life both hardy and dangerous, whilst in the plains we meet the agriculturist whose existence is one of peaceful monotony. In fact, turn as we will, when studying the physical causes which produce the greatest effect upon the human race we are confronted by conditions dependent upon geological structure.

If this reasoning is correct, and so much in a country depends upon its geological character, let us go one step farther and endeavour to find out what it is that produces the geological character itself. Should we pursue this question in all its details we should here enter upon a chain of reasoning which, in its collective form, embraces all that is known under the term Physiography. As a result of such an examination we should find ourselves face to

face with that molecular energy called heat, and this we might regard as potentially the producer of almost all the physical changes which the crust of the earth has undergone since the earliest times. On the one hand there is *sun heat* enabling the rivers and the oceans to wear away the land and pile up sediments. On the other hand there is *earth heat* causing elevations and depressions. By these two forces whole continents with their hills and valleys might be destroyed or formed. Should we wish to push our enquiries still farther we might do so, but our steps would be shrouded in a darkness which would make our path uncertain. Therefore rather than continue towards that region which is called "unknowable" let us pause and ask ourselves into what portion of the picture the outline of which has been indicated are we to insert our gleanings about earthquakes and volcanos.

Earthquakes are to us the evidences of sudden jars or blows which, having been struck upon the earth, cause a vibration to travel through a portion of its mass. During elevations or depressions rocky masses may reach their limit of elasticity, and being fractured give such blows. Volcanos are direct evidences of internal heat, and to those who study Physiography they are most important factors in all considerations connected with the internal condition of our earth.

In fact, earthquakes and volcanos belong to that portion of the world's history which tells us about its internal heat and it is to this heat and its fluctuations that nations owe the conditions under which they now exist.

If we then remember that the written history of a people, their character and their pursuits depend so largely upon the geological and physical features of the land in which they dwell, and that these in turn depend upon subterranean causes, the nature of which is best studied by examining earthquakes and volcanos as our witnesses, we shall see that the section of the world's history which has been taken up by the Seismological Society is sufficiently important to demand the attention of many workers.

Not only are we to regard volcanos and earthquakes as witnesses from which we are to extract information about the earth's internal heat upon which all we see upon the surface of the globe more or less depends, but we may look upon them as most important workers in producing minor changes of a local character. Volcanos have built up mountains and sometimes islands. And there is perhaps no place where these structures could be better studied than the country where we now reside.

To many lands volcanos have given a general aspect to the scenery, and by their sudden outbursts have excited terror and engendered superstition. Earthquakes have acted in a similar manner, and the fear which may be created by a shock of unusual severity is well known to all here present. In early times when these phenomena were ill understood, they seem to have excited the imagination and given rise to superstitious awe. It does not seem unlikely that the mountain worship of many countries may be in part the result of such early superstition. Certainly in this country we notice such worship to exist upon all high volcanic mountains, and in Peru we observe that the days on which the most serious earthquakes have occurred have been set aside as days for religious festivals; and the traveller still finds many of the North American Indians regarding their snow-clad and now extinct volcanos with a superstitious fear, the accounts of the eruptions of which could only have reached them by tradition. Farther, it does not seem unreasonable to suppose that these great phenomena, besides stimulating the imagination to the detriment of the understanding, may also have been active in creating hereditary timidity and thus to have become more or less a cause of mental aberrations like madness and imbecility. In other cases frequent shocks, by repeatedly giving rise to a feeling of insecurity, may perhaps have sown the seeds of recklessness and improvidence, which eventually have become characteristics of the nation.

The effect produced upon the weaker members of a community has recently been evidenced before our eyes, and *just*

as continued fear will work its result upon the individual, so may it produce a general effect upon the inhabitants of a country.

We have now briefly indicated the part which earthquakes and volcanos play in the various changes which go on around us. First, we see them as evidences of the internal conditions of the earth without which all our continents might long ago have been levelled with the ocean. Secondly, we see them as individual agents; the creative causes of islands, of mountains, and of great catastrophes, which latter have produced effects both physical any mental. If this then is the position the phenomena with which the Seismological Society have to deal occupy in the great scheme which we see going on around us, it now only remains to consider how far this portion of the picture which is before us has been filled in, and then set to work so far as we are able and endeavour to complete it.

Up to comparatively recent times we have had in an elaborate and exhaustive series of reports prepared by Mr. Robert Mallet for the British Association, an epitome and masterly coördination of all the facts which have been accumulated, and the results obtained in the department of seismic science since very early times. With the results of these reports which are founded upon varied analyses of over seven thousand recorded earthquakes, no doubt most of us are familiar. When looking at the results which have been arrived at, to use Mr. Mallet's words, we must not be discouraged "that after the vast labour bestowed by so many upon cataloguing earthquakes and discussing the results we find they do not even bring us to the threshold of positive knowledge."

Further on, in the conclusion of the same report, Mr. Mallet says "that a further expenditure of labour on earthquake catalogues of the character hitherto compiled, and alone possible from the data to have been compiled, is now a waste of scientific time and labour." The results which have hitherto been arrived at, so far as can be deduced from the cataloguing of earthquakes, are chiefly negative in their

nature, and "the main reward of toil so far is the having cleared away the rubbish," and shown us the roads in seismic science above which the sign "no thoroughfare" is written.

Lest any of us should be sceptical it would be well to remember that the opinions quoted are not those which have been based upon the work of any individual, but upon the works and investigations of some of the wisest heads in Europe.

To give a list of the names of these workers would only be repeating what we know already. Foremost among all these workers we have M. Perrey of Dijon and Robert Mallet each of whom have devoted a lifetime to the study of seismic science. The labours of the former of these workers have been carefully examined and criticised by a special committee of the French Academy of Sciences, whilst the writings of the latter have been laid before the British Association. Amongst the names of other contributors to this science we find those of Humboldt, Arago, Biot, Hopkinson, Schmidt, von Seebach, von Hoff, Falb, Fuchs, von Lasaulx, Credner, Vogt, Volger, Palmieri, Rossi, and many others too numerous to mention. At all times geologists, physicists, mathematicians, and men of science generally, have been attracted to the study of earthquakes; they have thought about them, and they have often written on them. Perhaps the best idea of the extent to which seismology has been studied may be gathered from the fact that Perrey, who himself has published some sixty memoirs on the subject of earthquakes, gave in 1856 a catalogue of one thousand eight hundred and thirty seven different works relating to earthquakes.

My reasons for mentioning how much has been done in seismology is to recall the circumstance that others have been in the field before us, and that before commencing any investigation, or putting forward any project, it behoves us, if we wish to avoid labour which may be fruitless, to make ourselves so far as circumstances permit masters of what has gone before.

If we turn to Vulcanology we shall find that the work which has been going on has been quite equal to that which has been done for the sister science.

What is of greatest interest to us dwelling in Japan is perhaps, the knowledge of what has been done and is, at the present moment, doing immediately around us. At first sight the work which has been accomplished may appear small; nevertheless when examined into we shall find that Japan has already contributed some valuable light to our knowledge of this subject.

Amongst the workers in Geology who have told us about the distribution of modern and old volcanic rocks, we have Mr. B. S. Lyman, who, in his voluminous reports, is leaving us a mine of valuable material from which the workers in Vulcanology may extract most useful and important facts. From these reports, coupled with a sketch map of the geological formations of Japan by Mr. J. G. H. Godfrey, together with my own observations, I made a rough sketch of the distribution of old and new volcanic rocks in the island of Nippon, and by cutting out the areas thus indicated and then weighing them against the remainder of the map, which represented country covered with sedimentary rocks, it would seem that the area of country covered by volcanic rocks is to that covered by sedimentary rocks as 2 : 3. That is to say, for the dweller in Japan, who is interested in the study of volcanic rocks, there is almost the same amount of rock exposed for his examination as there is for the ordinary geologist who confines himself to the rocks which are stratified and the alluvial plains. When we remember that these volcanic rocks build up nearly all the high mountains and to a large extent form the core upon which all the sedimentary rocks have been deposited, we see that the material which is before the members of this society waiting to be examined is almost unlimited.

Many of the rocks, which overlie these old volcanic rocks, are formed of a greyish clay like material which in nearly all cases can be shown to be the result of the decomposition of volcanic ejectamenta. Examples of this rock which is called a tuff, can be seen at Yokohama and rising up to form low hills on either side of the Bay of Yedo. Here it is usually regularly stratified, and has apparently suffered but little alteration since its deposition.

Now and then, as, for instance, in the harbour at Yokosuka, we can discover places where the continuity of the beds has been broken by a fault. As we trace these beds of tuff across the plain we see that as they near the hills they show signs of having been bent, and in many places they are broken. The extent of these breaks vary from a few inches to many feet. At the Kayanoma (Iwauai) coal-field Mr. Lyman has indicated a fault of about 400 feet of horizontal displacement, the existence of which fault has since been proved by mining. Now what do all these faults mean? When each of these breaks was produced was it announced to the surrounding district by a trembling and shaking of the ground? If it was, then those who have been engaged in mapping the faults which exist in various countries have really been drawing up for our inspection the records of byegone earthquakes whose energy has disappeared in molecular forces and heat. By the observation of faults it may perhaps be possible to make important inferences about earthquakes of times long past when the interior of the earth was hotter than it is at present, and was in consequence cooling and contracting more rapidly than it does now, so that possibly the giving way of its crust may have been much more frequent.

If we turn now to the volcanos we shall find that considerable work has been done. Of Japanese writers there are a vast number, and from a collection and a translation of their works much would be learnt. Amongst European writers on the volcanos of Japan we find the names of Messrs. Naumann, Marshall, Drasche, and Rein, and in all the books relating to Japan, like the valuable works of Siebold, Titsingh, and Kæmpfer, references to the volcanos of this country are numerous. Although several volcanos like Fuji and Asama have been described to us from the notes obtained by actual visits to the mountains, there are still a vast number of volcanos waiting similar treatment. In this department there appears to exist in Japan as excellent opportunities for observation as we could hope to obtain in any other portion of the globe. Volcanos can here be studied in all their stages. One year we may go to an island like Oshima

and only see a steaming fissure. The next year we may go, and in place of a fissure see a cone. Looking down from the heights above into the crater of this cone we may see the liquid lava welling from side to side, and have before our eyes an exhibition of the more immediate causes which cause volcanic outbursts. In other parts of the country we can see volcanos like Onsen near Nagasaki which, after killing half a hundred thousaud people and devastating provinces, are now resting their steaming flanks, as if collecting energy for another outburst. In another place we meet the mountain which is quite extinct and whose crater, with its placid lake, forms a haunt for summer tourists. Other volcanos again are remarkable for their size. This winter, while travelling in Kiushiu with Mr. Woolley of the English consular service I visited the volcano Asosan, which to my astonishment I found was a smoking hill rising from the middle of a crater which was approximately from *ten* to *fifteen* miles in diameter. To look into this crater was like looking into a huge pit, the perpendicular sides of which were from 300 to 1,000 feet in height. Although this central peak was smoking and only a few years ago threw out stones and ashes killing several men who were engaged in collecting sulphur near it, I calculated that there were living inside the crater out of which it rises, from ten to fifteen thousand people. Here we have a crater which does not seem to find its equal, in any that has hitherto been described unless we go to other worlds.

Not only are the volcanos of Japan remarkable for their size but they are equally remarkable for their form; their beautiful curvatures seem to show us that the shape of a volcano is due to the simple piling of loose material, shot out from a central vent rather than to secondary causes like those arising from subærial denudation. Farther, variations in these forms may perhaps indicate to us variations in the size and shape of an internal core, and it yet remains for us after having measured the external slopes of a mountain like Fujiyama to calculate the shape of the internal stony column which would be necessary to support it.

From volcanos I will now pass on to earthquakes which offer to us a field of inquiry which is almost unlimited. In nearly all the books which relate to Japan its earthquakes have in a general way been referred to. How far they have been thought about by the Japanese themselves is evidenced by the vast amount of literature which has been produced upon this subject, and more especially, perhaps, by the existence of earthquake calendars in the publication of which the people of Japan appear to have far outstripped the dwellers of all Western countries.

Lists of the names of many of these books and calendars have been given by Dr. Naumann and Mr. Hattori in papers they have written upon the earthquakes of Japan. Amongst others who have written specially upon this subject I may mention Messrs. Knipping and Chaplin. To endeavour to give an epitome of the results which have been arrived at by each of these writers, might not only be invidious but by its necessary brevity be an injustice to great labour. Therefore, rather than speak of them in detail, I will only refer in general terms to some of the more prominent portions of their investigations.

Ever since Seismology has been studied one of the chief aims of its students has been to discover some means which would enable them to foretell the coming of an earthquake, and the attempts which have been made by workers in this country to correlate these occurrences with other well marked phenomena may, I think, be regarded as attempts in this direction.

Ability to herald the approach of these calamities would unquestionably be an inestimable boon to all who dwell in earthquake shaken countries, and the attempts which have been made both here and in other places are extremely laudable. In almost all countries where earthquakes are of common occurrence these movements of the earth have been more or less connected with certain phenomena which, in the popular mind, are supposed to be associated with the approach of an earthquake. To give a full enumeration of these phenomena, many of which have reference to the state

of the weather or the seasons, would be to prepare a table of great length. Even in Tokio I have met with foreigners who will tell you that by a certain oppressive feeling, or by a sultry state of the weather, they have an instinctive feeling that an earthquake is at hand. When we remember that there are sometimes a dozen earthquakes in the month, if prognostications of this description never proved themselves correct we should have, I think, a defiance of the laws of chance.

To decide a question of this description in the minds of all, accurate records of these prophecies would need to be collected for a sufficiently long period of time for comparison with the records of an observatory. That the lower animals are affected by a shock, sometimes even a short interval of time before it actually become sensible to men is a fact almost beyond doubt. Many who are now present have heard pheasants scream a few seconds before we felt a shock as if they had perceived approaching tremors to which we had been insensible. That such tremors do sometimes precede a shock we may infer from the gradual manner in which shakings sometimes have a commencement, and also from the fact that in certain houses where the window sashes or slides are loosely fitted a rattling will be sometimes heard a few seconds before a shock is felt.

In Japanese records we read of the burrowing of moles before an earthquake, the rising of fish to the surface of the water, and other unusual movements in animals as having been observed to precede the phenomenon. To give a description of similar observations in other countries and cities referring to unusual movements which have been observed in dogs, horses, oxen, mules, pigs, geese and other animals before the coming of an earthquake, would take too long for the purpose we have before us. Another subject of interest, and one which has given rise to much speculation, are the movements of the barometer and thermometer which appear often to have been observed at or about the time of an earthquake. In Japanese accounts of earthquakes we read of unusually high temperatures, a largeness in the appear-

ance of the stars, mirage, illumination of the sea, and kindred phenomena as having occurred at or about the time of a great earthquake. In other countries sometimes a rise in the barometer has been observed; at other times a fall, and sometimes no change whatsoever. Before our last great earthquake we appear to have had a somewhat low barometer. If, however, we refer to the writings of M. Perrey as analysed by Mr. Mallet, we shall see that there have been as many instances where the barometer fell as where it did not fall, and we are led to the irresistible conclusion that as yet we have not sufficient foundation on which "to base a law with respect to the behaviour of a barometer during an earthquake." However, that a relation may exist is not improbable. That there is a momentary *mechanical* movement in a barometer at the time of an earthquake is a fact very distinctly shown upon the curves drawn by the barograph at the Yamato-Yashiki observatory.

With regard to the thermometer and the connection of its movements with earthquakes we again find ourselves unable to establish any rule. The Greeks and Romans believed that earthquakes were most prevalent in the warm seasons while we believe they preponderate in the cold. If we tabulate all the records we are able to obtain of earthquakes which have occurred in Japan since early times, we shall find that the greater number of them have happened during the warm seasons, whilst if we tabulate the smaller earthquakes which are now being recorded we shall find that the greater number happen during the winter months.

In what manner changes of atmospheric temperature can be connected with earthquakes it is difficult to conceive, unless, as has been suggested, they may sometimes indicate a local overheating of super volcanic districts. Changes like these, however, assuming them to exist, could hardly be supposed to be unconnected with the seasons.

The relations between the rainfall and earthquakes of Japan which have been sought, do not appear to have, as yet, shown any satisfactory connection. It does not seem to be altogether beyond the pale of possibility that the rain

which falls upon a volcanic country may have an influence either in soaking downwards and becoming converted into steam, or in simply loosening the ground. From personal experience I have found that microphones buried in pits during a heavy shower of rain are sometimes very active, as if by the soaking downwards of the rain and perhaps the falling in of small particles of earth from the side of the pit the microphones had been slightly shaken.

At the time of earthquakes, high winds have often been observed, and from the tables given to us by Mr. Knipping it would appear as if these two phenomena had been synchronous. About the electrical effects which are produced at the time of an earthquake we have as yet but little record, nevertheless from what has been observed in other countries there is every reason to believe that we have in Japan the means of making observations which may lead to interesting results. The momentary current produced in cables and telegraph wires at the time of an earthquake was brought before our notice some years ago by Mr. W. E. Ayrton in a communication to the Asiatic Society. In Japan it is a popular belief, and a belief which is said to be founded upon well authenticated observation, that shortly before an earthquake a magnet is affected by losing its power of attraction. Analogous effects appear to have been observed in other countries, and amongst those who have remarked upon this subject we may note the names of Humboldt, Arago, and Biot. So far, the conclusions which have been arrived at appear to be that the observed disturbances are due rather to mechanical agencies than to variations in magnetism. However, as the belief that there is a connection between earthquakes and magnetic force has taken such deep root in the minds of many who dwell in earthquake shaken countries, although we can only dimly discern the possibility of such a connection, the subject appears to be worthy of investigation.

In the accounts of some Japanese earthquakes, mention is made of the appearance of luminous bodies in the sky and shooting stars. Humboldt and Mallet have each made reference to similar phenomena, but the results obtained distinctly

show that there have been many more earthquakes unaccompanied by such appearances than occurring with them. In Dr. Naumann's valuable paper on the earthquakes of Japan, reference is made to the same subject, but the results obtained, although in many case showing connections to exist, are of such a nature that the question nevertheless appears to remain open. Notwithstanding the observations of Wolf a similar remark may be made with regard to the connection which exists between the periods of earthquakes and those of sun spots.

The connection which might exist between earthquakes and the sun and moon was many years ago worked out by M. Perrey, and his results examined by a commission appointed for the purpose by the French Academy of Sciences. It was supposed by M. Perrey that the sun and moon exerted an attractive force upon the crust of the earth, just as it does upon the waters of the ocean, and caused it to swell until meeting with resistance, the formation of fractures resulted and hence the production of earthquakes. By analysing the various catalogues he had collected, and comparing them with the motions of the moon, amongst other results which were arrived at, he came to the conclusion that earthquakes were more numerous when the moon was in perigee than when in apogee. To these results, however, an anomaly now and then presents itself, and no better example of such an anomaly could we have than that which has been pointed out by Mr. W. S. Chaplin in regard to the earthquakes which have recently occurred in this country, which are in utter discordance with any of the results obtained by M. Perrey.

Thus far, then, it would seem that the curves and tables which have been drawn in Japan, like those which have been made in other countries, have not, as yet, brought us to any definite results, and so far as we have gone we have only reached conclusions similar to those expressed in 1850 by Mr. Mallet, who then said, as the result of his investigations, that "earthquakes and volcanic eruptions may occur at any time of the day or year."

If such, then, is the case would it not be well, whenever problems like these we have been considering are brought before us, to attack them first in an opposite direction, and, instead of first collecting facts and then reasoning up to generals results, to picture to ourselves the result we are endeavouring to reach and then inquire whether it would be reasonable to seek for facts which would lead us to it. For example, let us suppose ourselves searching for a connection between earthquakes and the attractions of the moon; instead of at once proceeding by the accumulation of facts to see if such a connection had a reality, might we not proceed backwards, and ask ourselves if it would be reasonable to expect that a result like this could ever be attained? Is it likely that the attractive power of the moon is so great that it could draw up the crust of the earth beyond its elastic limits? We know what it can do with water. It can lift up a hemispherical shell 12,000 miles in length about two or three feet higher at its crown than it lifts the earth. Even supposing the solid crust to be lifted 100 times the apparent rise of the tide is it likely that a hemispherical arch 12,000 miles long when it is raised 200 feet at its crown could by any possibility suffer fracture? If an arch is 12,000 miles in length all that we here ask is whether the materials which compose the arch are sufficiently elastic to allow themselves to be so far stretched that the crown may be raised two hundred feet. The result which we should arrive at is apparently so obvious that actual calculation seems hardly necessary. If we regard the earth as being solid, the question resolves itself into the inquiry as to whether a column of rock, which is equal in length to the diameter of the earth, or about 8,000 miles, can be elongated two hundred feet without a fracture. This is equivalent to asking whether a piece of rock one yard in length can be stretched one seventy thousandth of a foot. Considering that this is a quantity which is scarcely appreciable under the most powerful of our microscopes, we must also regard this as a question which it is hardly necessary to enter into calculations about before giving it an answer. To vary the method of treating such

a question might we not ask what is the utmost limit to which it would be possible to raise up, or stretch the crust of the earth without danger of a fracture? Thus, for instance, to what extent might a column of rock be elongated without danger of its being broken. From what we know of the tenacity of materials like brick and their moduli of elasticity, it would seem possible to stretch a bar of rock 8,000 miles in length for approximately half a mile, before expecting it to break. As to whether there is a wave the height of which is equal to half this quantity running round our earth as successive portions of its surface pass beneath the attracting influence of the sun and moon, is a phenomenon which, if it exists, would probably long ago have met with a practical demonstration. Finally, knowing the mass of the moon and the other bodies which exert any important influence upon the earth, we might calculate at any time their attractive force and if this were done I think we should find that the stretch it might produce was something far below the elastic limits of the materials on which it acted. We might therefore perhaps conclude that influences like those we have been considering would if taken by themselves be far too small to directly concerned in the production of earthquakes. How far they might be influential in causing shocks to take place at particular *times* is another question, the answer to which might be conceived of by first answering the questions already given. The cases which I have here chosen are purely hypothetical and are only brought forward to illustrate the manner in which such a subject might be treated.

The deformation which a spherical shell or solid globe like our earth would experience under the action of a body like the moon has already been treated mathematically by Lamé Thomson and others and it would seem that much might be derived, by attacking many other questions which are analogous to it in a similar manner.

If we now turn from the observations themselves to the instruments which were used to make them. I think that young as we are in the world of seismic science, we shall see around us a mighty forest of pendulums, springs, and

delicately balanced columns, all intended to indicate some of the phenomena which accompany an earthquake. For the small shocks which so often visit us Mr. Knipping has found, and I think that Mr. Chaplin and I support him, that any of the simple seismometers, like columns perched on end, are but of little value as indicators. Let our columns be so small that it is with difficulty we can make them stand, yet strange as it may appear, it is but seldom that they fall. And even when they do fall, it is often difficult to say that they indicate to us any thing more than the fact that there had been a shaking. If we could guarantee their having fallen at the first impulse by their bases having been, so to speak, swept from under them, then not only would they tell us the direction of the shock, but also the point from whence it came. In small columns such as it is necessary to have if we are to expect any effect whatever, there are the mechanical difficulties of obtaining a base which shall be perfectly flat and at the same time at right angles to its axis. If these conditions are not fulfilled, the direction in which we find our column lying after a shock will indicate but little. What is required is to have a column with a base so large that it can be easily stood on end, and what is more important, to make the column of such a shape and height that for its maximum "tip" it shall have a period quicker than that of the earthquake. By making columns of different shapes this has been to some extent, accomplished.

Amongst the instruments of a more complicated nature, we may mention Palmieri's well known assemblage of springs and pendulums, of which we have an example working at the government observatory of Yamato Yashiki. Amongst private workers a heavy pendulum appears to have been a favourite instrument, and at the present moment there are perhaps a dozen of such instruments which have been working for some time.

In nearly all the older instruments which have been constructed upon the principle of a pendulum, it has been assumed that during a shock the pendulum would swing, and that the first swing would indicate to us the direction

of the earth's motion. From numerous experiments upon upon pendulums varying in length from thirty feet down to one foot, experiments that have been confirmed by other observers, I find that during the small shocks which are felt in Tokio, no visible swing is to be observed. If, however, the shock is strong and long, like that recently experienced, a motion is gradually got up, and a pendulum, even if it is forty feet in length, and loaded at the end with a weight of 80 lbs., like a pendulum which, through the kindness of Professor Marshall, I have been experimenting with in the Physical Laboratory of the Kobu Dai-Gakko, will get up a long and steady swing. This appears to be due to the swing of the building in which the pendulum is suspended, being nearly in unison with the period of the pendulum. The reason that these pendulums do not swing during a small shock is apparently because their period of vibration is long compared with that of the earthquake, and that the house in which they are suspended to a great extent absorbs the vibrations by the viscosity of its joints and thus prevents any movement in the point of support. During a small earthquake it would therefore seem that we may regard the bob of a heavy pendulum as a steady point above the moving earth. In two pendulums which I have suspended, the motion of the earth is recorded by a pointer from the pendulum marking upon a piece of smoked glass moving beneath it. In a third pendulum the motion of the earth is indicated by the earth pushing a small pointer against the steady pendulum; the pointer being moved, a mirror with which it is in contact, is caused to revolve and deflect a beam of light. In Dr. Wagner's apparatus which so far as I am aware is the first where the pendulum principle in conjunction with a mechanism for magnifying the earth's motion and for checking any oscillations of the pendulum has been employed, we have a pendulum below which there is attached a second smaller pendulum or lever the shorter arm of which works in the base of the pendulum above it. The longer arm of this lever magnifies the earth's motion; a second portion of the apparatus gives a close approximation to the

direction of the shock, and a third portion the vertical motion. To understand the working of these several parts it will be well to refer to their description as given by Dr. Wagener himself in the communication referred to at the end of this paper.

Mr. Ewing's seismograph, which he is about to exhibit to the society, is designed to draw two curves representing on a magnified scale two rectangular components of the horizontal movement of a point on the surface of the earth, in conjunction with the time. These curves are drawn by means of two levers, with their short ends in contact with the bob of a long pendulum, and with their long ends free to slide across two surfaces which are kept moving continuously and uniformly by clockwork.

In Mr. Gray's apparatus small threads are carried from the end of the bob to small pulleys with pointers. These pulleys being drawn away from the pendulum during the motion of the earth, they are caused to revolve. The pointers are then left in the position to which they have been moved. As this pendulum is attached at its upper end to a strong spring, a vertically placed thread from the centre of the weight to a pulley fixed above the point of suspension, tells us something about vertical motion.

The first pendulum observations which were made in Japan appear to have been by Dr. Verbeck in 1872 and 1873 who used a pendulum about six feet in length. This investigator also used a heavy block of wood resting on four crystal balls, the whole being carried on a marble slab. At the time of an earthquake the block of wood by its inertia remained stationary and by means of a sliding pencil marked the motion of the earth upon a sheet of paper placed upon the moving slab.

With machines such as these, many measurements which tell us something about the actual horizontal motion of an earth particle have already been obtained. As examples of such observations I give the following.

The first four are taken from my own observations, whilst the second three are some which have been observed

by Mr. Knipping as recorded by the instrument of Dr. Wagner.

	1.	2.	3.	4.
Date	1879, March 4th	1879, October 18th	1879, October 25th	1880, February 1st
Time	4.43 p.m.	2.0.11 a.m.	0.39.0 a.m.	11.0.0 p.m.
Extent of motion	2 mm.	4 mm. to 5 mm.	4 mm.	1.25 mm.
Direction	N. 10° E. to S. 10° W.	N. N. W. to S. S. E.	N. 28° E. to S. 28° W.	N. 25° W. to S. 35° E.

	1.	2.	3.
Date	1879, October 17th	1879, November 22nd	1879, December 3rd
Tokio Meantime	13 h. 58 m. 30 s.	9 h. 25 m. 42 s.	19 h. 8 m. 18 s.
Greenwich Meantime	4 „ 39 „ 22 „	0 „ 6 „ 34 „	9 „ 49 „ 10 „
Maximum Horizontal Movement.	2.3 mm.	1.7 mm.	4.3 mm.
Maximum Vertical Movement	.06 „	.0 „	0.13 „
Total Movement	2.3 „	1.7 „	4.3 „
Angle of Emersion	1.6°	.0	1.7°
Direction	N. 1° E. to S. 1° W.	S. 80° E. to N. 80° W.	S. 21° E. to N. 21° W.

Hitherto the amplitude of an earth particle appears only to have been obtained from inferences based upon the extent to which fissures have been formed in non-elastic masses of

masonry and brick work. If this is the case, we may congratulate ourselves upon having already made an important advance in seismic science.

In all the instruments which have hitherto been employed in Japan one or two principles appears to have been followed. First, we have had instruments whose operation, so to speak, depended upon a certain portion of their parts remaining steady. Of this class we have the pendulums just described. We also have a heavy weight suspended at the end of a bracket as experimented on by Professor Chaplin. In the other class we have bodies whose main feature is their movement, amongst which we have the swinging pendulums, both liquid and solid, and falling bodies like columns. The year before last a new principle was brought before us by Messrs. Perry and Ayrton who, with great justice, described it as a "neglected principle." Its feature appears to be as follows:—If we take a vibrating body like a spring and it be set in motion during an earthquake, not only will it have a motion of its own, but it will have a compound motion, the components of which are its own natural vibrations together with those implanted upon it by the earthquake, and knowing what the former of these is, the latter may be separated by analysis. The true principle involved, as ennunciated by the authors, may be understood by the following two illustrations.—Let a man walk across a springy plank. If he walks quickly or attempts to run, the motion of the plank will not synchronize with his steps, and he will be in danger of losing his foothold. If, however, he walks slowly, the plank will give with each of his steps, and register the periodic motion of his movements. Now if we imagine the steps of the man to represent the vibration of an earthquake, we see that these can only be distinctly reproduced upon a spring like the plank when the period of the earthquake is less than the period of vibration of the spring. If, therefore, we wish to imitate the earthquake motion by means, say, of a ball fixed upon a spring, this spring must have a quicker period of vibration than that of the earthquake.

Hitherto all earthquake machines which have been in any way dependent upon springs have had slowly vibrating springs, so that the earthquake motion, if it had ever been extracted from the results which were obtained, would appear like ripples upon the sides of large waves.

Here is an illustration in which both the old and the new principles are combined. Let any one shake a young tree. The trunk, which is naturally a stiff, quickly vibrating body, will shake with periods which are given to it by the shaker, whilst the branches will all have different motions, depending on their thickness, position and length. The thin ones will nod to and fro with a slow period of their own, whilst the thicker ones will move more quickly, and if their natural period of vibration is quicker than those vibrations which are given to them by the trunk, they also will record the motion of the shaker. Where a tree is shaken by an earthquake exactly the same thing will occur, the trunk and thick branches are very likely to move with it, and record its motion, whilst the thin branches nod to and fro with motions of their own.

Now many of the earthquake instruments which have hitherto been constructed, seem to work on the same principle as the thin branches, whilst that proposed by Messrs. Perry and Ayrton is represented by the thicker branches and the trunk. One simply shows that there is a motion whilst the other gives the real motion.

The paper of Messrs. Perry and Ayrton has suggested to us an instrument which will give us time observations, of the number of vibrations which occur in any given, interval, and their relative amplitudes. From the fact that a machine of this description has not yet received a trial, it is sincerely hoped that the members of the Seismological Society may speedily have an opportunity of testing an instrument which promises so much.

If we except those seismometers which may be constructed on the principle just mentioned, the difficulty to be overcome appears to be, in obtaining at the time of an earthquake a steady body upon which to write the observations, of

the moving earth, or, *vicè versa*, to obtain a steady body from which, by means of a pointer, we can trace out the motion of the moving earth upon itself. In the case of pendulums if it is found that the point of support receives so much motion that they are caused to move. This to a great extent might be obviated by depending the point of support from a net-work of india rubber bauds, which net work might, in turn, be depended from a second set of bands, the numbers being increased until found sufficient to eat up all small vibrations of the earthquake. It has been suggested that a similar result might probably be arrived at by a series of pendulums dependent from each other, the periods of each being incommensurable with the one immediately above it, and the top one with the period of the earthquake. As a third method of obtaining a steady point at the time of an earthquake, it might perhaps be possible to use a gyrostat.

With regard to the period of an earthquake, that is to say, the rapidity with which its vibrations succeed each other, I may remark that, although no results upon this subject have hitherto been published in Japan this interesting problem has, for some time past, been a subject for speculation and work. Besides the moving plates beneath the large pendulum, which have already roughly indicated facts which will be useful in the solution of this problem, experiments have been made with a number of extremely short pendulums to determine which of them, by its movement, was in accordance with the movement of the earthquake.

As other methods of attaining the same result, Mr. Gray and myself are using a number of vertical springs so loaded that their periods of vibration are different, and it has been already shown by the last few earthquakes, that it is only springs of particular periods which are caused to vibrate.

Another interesting study for those living in earthquake shaken districts are the effects which are produced upon buildings, and the best means to be employed for avoiding such effects. We are all no doubt acquainted with the system which is employed by Mr. Lescasse in order to render a building proof against all ordinary shakings. As an

example of such a building we have the offices of the Mitsu Bishi Company now in process of erection. As another example of work in the same direction we have the pamphlet of Messrs. Perry and Ayrton who discuss the principle of relative vibrations in the various parts of a building. I may here remark that the actual vibration of a wooden house during the last great earthquake, seemed to accord with the calculated vibration as given by the above authors.

With regard to the cracks which have been produced in buildings, I may remark that they form an interesting subject for investigation. In making observations on a large number of houses in the neighbourhood of the Ginza, and for assistance in making which observations my best thanks are due to Mr. Josiah Conder who accompanied me, I found that the greater number of cracks were visible in those streets which were traversed parallel to their length by the greater number and the more severe earthquakes, whilst the streets at right angles to them had suffered least. Several of the more modern and elaborate constructions which we have in Tokio have also been examined, but about these nothing has, as yet, been published.

Before concluding, as it may be of interest to many who are here present, I will make a few remarks about a scheme which is now being carried out with regard to the earthquakes which visit the district round Tokio and Yokohama. This I will supplement with some speculations as to probability of our ever being able to forewarn ourselves with regard to such phenomena.

Through the interest taken in Seismological Science by Mr. Yamao Yozo, the minister of public works, fifteen seismometers of the pendulum type as designed by Mr. Gray, are now being constructed for the purpose of distribution over the plain of Musashi. Through the kindness of Mr. Ishie, the director of the telegraph department, these instruments are to be placed in the telegraph offices, where, by means of clocks which are every day regulated by Tokio time, not only will the earthquake movement be recorded, but the times at which the shocks are felt will be also noted,

By this means it is hoped to obtain very close approximation to the actual movement at each place. The relative movements at different places will also be known, the determination of which latter fact will, in itself alone, be sufficient to place Japan among earthquake shaken countries in the first ranks of those which have paid attention to observational seismology.

From the direction of the shock as observed at different stations its *epicentrum* may be found, and the district or districts from whence come all the shocks we so often feel may be determined. Time observations might bring us to similar results, but what is of more importance, they will give us the rates at which a given shock is propagated in different directions, and by variations in these rates we may obtain a clue as to the nature of geological formations buried deep beneath our view.

The determination of problems like these are of the greatest interest to science, and the practical results will be of value to the geologist, the builder, and the engineer.

Let us now proceed a step farther and enter into what many would call pure speculation. Supposing that the areas from which the shocks originate which so often visit us were localised. I think if we were to place our seismographs on such a spot we should record many earthquakes which are too feeble to travel far out into the surrounding districts. In Yokohama earthquakes are felt which seemingly expend their energy and die out before reaching Tokio. On the area from which these feeble shocks have emanated it is not at all unlikely that still feebler shocks might be recorded which could not even reach Yokohama. And if in such a district we were to use some form of micrometric seismograph, we might perhaps record such feeble tremors to which the ordinary seismometer would have been insensible.

Next let us ask ourselves what is it that produces the earthquakes and earth tremors in a seismic district? Is the ground continually crackling and breaking as it bends beneath increasing strains, as for instance the expansions and contractions produced by a flow of heat? If this is so,

observations upon earth temperatures may possibly yet become the means of indicating to us the approach of breakages which snapping the rocky crust give rise to earthquakes. Whether by observing the temperature of hot springs we may come to similar results, it is difficult to say. In every probability hot springs represent to us the escape of water from reservoirs under pressure, and when such is the case variations in the temperature of the waters underground could net well be expected to show themselves in the water as it escaped at the surface. If underground temperatures are to be derived from sources such as these the springs must be well chosen. Mr. Arai Ikunosuke the director of the observatory at Yamato Yashiki I am happy to say has the intention, when a suitable opportunity presents itself, of putting these suggestions to the test. I am informed that in Bourbon they have yielded results which are highly satisfactory.

Instead of working with earth temperatures we might perhaps, be more successful if we formed a study of earth *remors* which may possibly be found to indicate the breaking of the ground as crackling indicates the breaking of a stick.

These are hypotheses which yet need careful study, but should they ever prove to be correct, as the temperature or crackling in a seismic area increases, we may yet see a large black ball gradually ascending a tall staff to warn the inhabitants on land of an approaching earthquake, with as much certainty as the ball upon a pole at many sea-ports warns mariners of storms at sea.

I have already stated that the relations which have been sought as existing between earthquakes and phenomena, like the motion of the moon, the rise and fall of the barometer and the like, are as yet too indefinite to be considered as established. As the attempts to establish these connections have been numerous, would it not be well to vary our operations, and see if the laws for which we have been searching may not be found by comparing the occurrence of earth *tremors* and these phenomena rather than earth *quakes*?

When we consider the nature of the pull which the moon exerts upon our planet, we are more likely, I think, to find a connection between its motions and earth *tremors* of some sensitive district, than between such periods and earth *quakes*.

As the earthquakes which produce sea waves, of which the old residents in Japan have had several experiences, often take place at such great distance, it ought often to be possible by means of the telegraphs which are now stretched in all directions to forewarn ourselves and others of the approach of the waves notwithstanding that they traverse deep oceans at the rate of several hundred miles per hour. About May 11th, 1877, a series of sea waves swept in upon the shores of all the islands in the Pacific, from New Zealand in the south to the Kuriles in the north. Here and there where the bays were long and narrow the waters inundated villages, and the property which was destroyed was very great. This particular series of waves, we subsequently learnt, originated on the coast of South America, on May 9th, and having to traverse 8,000 miles of ocean before they reached Japan they had taken more than 24 hours. An example like this shows us that telegraphic communication might easily be made the means of providing against calamities arising from such an origin.

On a smaller scale if it should be thought desirable we might, in a similar manner, warn ourselves against many land shocks. For a shock to travel from Yokohama to Tokio, passing directly through the two places, it would have to traverse about fifteen miles of soft earthy and rocky strata, to do which it would probably take a minute and a half. Round Tokio and Yokohama we have at the present a ring of telegraph stations at distances of from 20 to 60 miles. To cause a shock as it passed any of these stations to complete an electric circuit would be a matter very easy to accomplish. Such a current being completed it might almost instantaneously be made to fire a gun in Tokio or Yokohama, and the inhabitants of these places would thus have

from two to six minutes warning of at least a large proportion of all the shocks which visit them. The nature of the shock which was to be expected would, to a great extent, depend upon the adjustment of our instruments. If the instruments were delicate we might often be alarmed at hearing the report of a cannon and afterwards only receive a tremor. To make a contrivance like this practical it would be necessary so to construct it that the circuit could only be completed by a shaking that was tolerably severe, and that the cannon had a report easy to distinguish. These last remarks have been made, not with the hope that I shall ever see them realized, but with the hope that they may help to convince those who regard the foretelling of an earthquake as a problem too difficult to be solved, and to show them it is by no means so utterly beyond our reach as might, at first sight, be anticipated.

And now I will conclude. What I have attempted has been to show the position which the study of earthquakes and volcanos occupy in the scheme, waiting to be worked out, for the elucidation of the natural laws upon which all terrestrial things appear to be dependent.

After this I have given a condensed summary of the work which has been done in this country towards carrying out this scheme, in doing which it is my sincere hope that brevity has not led me into inaccuracy or injustice.

The study which is before us is extremely great, and is one which offers a wide field both for observation and speculation. Hitherto, although the facts which have been amassed are very numerous, the results which have been obtained are comparatively small. One cause which has undoubtedly been powerful in preventing advancements such as those which characterize other departments of science has been the fact that seismic and volcanic phenomena have never been prominently brought before those nations distinguished by their attention to scientific subjects. Here, however, in Japan we have a large body of men, all of whom are more or less interested in scientific matters, dwelling in a country where these phenomena, are ever present. The

field to work in is large, and as we are in it, it is earnestly to be hoped that we shall take advantage of our opportunities and, by endeavouring to unravel some of the tangled problems of seismic science and by increasing knowledge, add at least a mite to the understanding of those laws which ameliorate the conditions under which we live.

Note.—RECENT PUBLICATIONS ON THE EARTHQUAKES AND VOLCANOS OF JAPAN, REFERRED TO IN THIS PAPER.

Proceedings of the German Asiatic Society. (Mittheilungen der Deutschen Geschellschaft für Natur und Volkerkunde ostasiens.)

14tes Heft.—"Verzeichniss von Erdbeben, wahrgenommen in Tokio, Japan, in 35° 41′ N. B. 139° 47′ O. L. v G. von September 1872 bis November 1877 von E. Knipping.

15tes Heft.—"Ueber Erdbeben und Vulcanausbrüche in Japan, von Dr. Edmund Naumann.

15tes Heft.—"Bemerkungen ueber Erdbeben messer und Vorschlaege zu einem neuen Instrumente dieser Art," von Dr. G. Wagner.

Transactions of the Asiatic Society of Japan.

Vol. II.—Also. Vol. III, Part II.—Constructive Art in Japan' by R. H. Brunton, Esq.

Vol. V, Part I.—"On a neglected principle that may be employed in earthquake measurements," by John Perry and W. E. Ayrton.

Vol. VI, Part II.—"Destructive Earthquakes in Japan," by I. Hattori, Esq. "Notes on some of the Volcanic Mountains in Japan," by D. H. Marshall, M.A. "An Examination of the Earthquakes recorded at the Meteorological Observatory, Tokiyo," by W. S. Chaplin, Esq.

"Some remarks on constructions in brick and wood, and their relative suitability for Japan," by George Cawley, Esq.

Geological Magazine.

Dec. II. Vol. I No. 5.—"A visit to the Volcano of Oshima," by J. Milne.

Dec. II. Vol. V No. 8, also Dec. II. Vol. VI No. 11.—"On the form of Volcanos," by J. Milne.

Dec. II. Vol. VI. No. 8.—"A cruise among the Volcanos of the Kurile Islands," by J. Milne.

Other Publications.

"Reports of the Geological Survey of Hokkaido" by Benjamin Smith Lyman.

"Reports of the Geological Survey of Japan," by Benjamin Smith Lyman.

Pamphlet printed at the Imperial College of Engineering, Tokei, Japan. "On Structures in an Earthquake country," by John Perry and W. E. Ayrton.

Pettermann's Mittheilungen 1876, Heft. 10. "Der Fujiyama und seine Besteigung" von J. Rein.

Deutschen Geologischen Gesellschaft, 1877. "Die Vulcaninsel Ooshima und ihre jüngste Eruption," von Herren Edmund Naumann in Yedo.

Mineralogische Mittheilungen 1877. 1 Heft. "Bemerkungen ueber die Japanische Vulkane, Asama Yama, Takiyama, Iwa-wasi Yama und Fusi Yama." Von Dr. Richard von Drasche.

"An Essay on Japanese buildings and on buildings in general, considered in connection with earthquakes; and a description of a system designed to give security to constructions in masonry," by J. Lescasse. Published in the *Japan Gazette*, March 29th, 1877.

The earthquake of Dec. 3rd, 1879. *Japan Gazette*, Dec. 13th, 1879.

The earthquake of Feb. 22nd, 1880. *Japan Gazette*, Feb. 24th 1880.

THE chairman said he was certain that in tendering thanks to professor Ewing for his elaborate description of the new seismograph he only echoed the sentiments of the meeting. The general principal of the instrument was similar to that of the heavy pendulum, and the main question was whether or not the pendulum will oscillate or whether it remains steady and thus allows the vibrations of a small earthquake to be recorded. In Tokio a number of light shocks have been felt which failed to set a heavy pendulum in motion; but by a severe shock the same pendulum oscillated through a large angle. In professor Marshall's laboratory there was a pendulum forty feet in length, which was set in motion by the late severe earthquake and kept oscillating for a period of eight hours. He (the chairman) was of opinion that professor Ewing's machine was much better than any instrument of the kind which had come before his notice.

Professor Knipping said that with regard to what professor Ewing had mentioned about the suspension of the heavy pendulum, he quite agreed with him that the point of suspension should be as rigidly connected with the earth as possible, so that every movement of the earth's surface should also be made at the same time by the point of suspension. But the length of the pendulum in Dr. Wagner's apparatus was not nearly twenty feet, as that of Professor Ewing's, but was only about three feet long; and from observations made during a period of about two years he (Mr. Knipping) was rather confident that a pendulum three feet in length was quite long enough. It was not every person who had a clear height of twenty feet at his command; and even if he had that height at his disposal, it would require a very broad basis of strongly bound frame-work to prevent the point of suspension going its own independent way in an earthquake. Although the apparatus he had been observing

for some years could give no direct and positive proof of the pendulum remaining in the same place in space during an earthquake, while the point of suspension moves to and fro, there has been nothing observed yet which points to the contrary, while everything is in its favour. Another apparatus, still in course of construction, will very likely prove definitely whether we are right in assuming that in moderate and even in strong earthquakes, a heavy pendulum remains practically at rest. But even should it be proved afterwards that in extreme cases the heavy pendulum commences to swing, instead of remaining at rest, he was not of opinion that the whole apparatus should be rejected. Even such observations may be used; and it is possible to separate in the diagram made by the instrument that part due to the earthquake motion from the other part due to the swing of the pendulum. Dr. Wagner's apparatus, described in the 15th vol. of the "Mittheilungen der Deutschen Gesellschaft," consists of several parts,—

1st.—For the greatest horizontal motion of a point in the earth's surface; at the same time it arrests a clock.

2nd.—For the greatest vertical motion.

3rd.—For the direction in azimuth.

4th.—A registering apparatus for marking the duration and intensity of each vibration, and also the duration of the whole earthquake. No. 4 has not yet been put up, but 1 to 3 have been some time at work and seem to answer very well.

Professor Mendenhall said he thought that there ought to be some systematic method of examining such machines as that which had been exhibited by professor Ewing, and the committee of the society had thought it advisable that such instruments should be submitted to a sub-committee, who should make an exhaustive study and elaborate report on the machines. And as they had now a very interesting and valuable seismograph, he rose to move that a committee of three be appointed to examine this instrument; and that this committee shall examine into and report on the value of the following points:—

Value of results to be obtained by its use.
Scope or comprehension of these results.
Reliability of the results.
Sensitiveness.
Simplicity of operation.
Simplicity of construction.
Cost of construction.
Skill required in its use.
Any other points of interest or importance.

These were some points which he (professor Mendenhall) had noted down, and they might be taken with any others which would suggest themselves to the committee. The committee should make the examination and give in their report at as early a date as possible.

Professor Ewing said that he should have much pleasure in giving every assistance in his power to such a committee. He had not the slightest objection to having his instrument reported upon, but begged to remind the meeting that it was not yet completed. The room in which it was to be placed was not finished, neither was the clock which had to drive the mechanism. It was, therefore, not in a fit state for examination, and on that account he thought professor Mendenhall's motion rather premature. He also thought that in all cases when a committee is appointed to report on an instrument, that their report should be submitted to the inventor, who should have the privilege of criticising such report simultaneously with its presentation to a public meeting.

Professors Knipping, Marshall and Chaplin were then appointed a committee to examine into the merits of Professor Ewing's invention.

There being no other business the meeting adjourned, after having sat for nearly two and a half hours.

A NEW FORM OF PENDULUM SEISMOGRAPH.

By J. A. Ewing, B.Sc., F.R.S.E.,

Professor of Mechanical Engineering in the University of Tokio.

(Read April 26th, 1880.)

The object of the present paper is to describe a seismograph of the author's design, which has been erected in the university of Tokio. The instrument is intended to register graphically the horizontal movement of a point on the earth's surface during the whole of any seismic disturbance. For this purpose two continuous curves are automatically drawn, showing on a greatly magnified scale the extent of displacement in two directions at right angles to each other, in conjunction with the time. From these it is easy to determine the total movement at any time during the disturbance, its direction and its velocity.

The instrument consists of a long pendulum having a massive bob with which the short ends of two multiplying levers are kept in contact. The fulcrums of the levers, being rigidly connected to the earth, move with it, and (on the assumption that the bob of the pendulum remains at rest) their long ends will move through distances which are certain multiples of the component displacements of the earth's surace. The levers are placed at right angles to each other and are so arranged that each is affected only by the component displacement in its own direction. The long end of each lever is in contact with a smoked glass plate which is revolved continuously by clockwork. When an earthquake takes place the levers move out and in along the radii of the glass plates,

and thus curves are drawn, showing the relation of displacement to time in two directions, throughout the whole disturbance.

The bob of a pendulum used as a seismometer is liable to be set in motion during an earthquake by either of two causes. First, by the resistance of the recording apparatus due to friction and inertia, and second, by the motion of the point of support, and the consequent effect of gravity upon the bob.

To avoid as far as possible the first of these disturbing causes, the recording lever should be made exceedingly light, relatively to the mass of the bob, and the friction both at the fulcrum and at the recording point should be made as small as may be consistent with definiteness of support and distinctness of record.

Moreover, it is of the greatest importance that the point of contact between the recording lever and the bob should be as near the centre of gravity of the latter as possible, or at least that the line of action of the resistance to motion of the recording lever should pass through the centre of gravity of the bob. Otherwise a motion of the bob, not as a whole, but of one part relatively to another, will be induced. In some of the author's earlier experiments a spherical bob was used and the recording lever was kept in contact with the foot of it. It was found that a sudden displacement of the fulcrum of the lever produced a rotation of the bob about a horizontal axis, which, although the recording lever offered very little resistance to motion, was sufficient to completely falsify the record. In the instrument as it now exists, the bob acquires no sensible motion of any kind on account of the resistance of the recording apparatus.

The second of the two causes of disturbance mentioned above will be excessively great if at any time during the shock the point of suspension of the pendulum makes its oscillations in times equal to or multiples of the periodic time of the pendulum, but will be felt only very slightly if the period of the pendulum is greatly in excess of that of the motion of the point of suspension. Little is as yet known of the

length of time occupied in each oscillation of a point on the earth during an earthquake, but it is probably only a fraction of a second in most cases. If, therefore, the point of suspension could be connected quite rigidly to the surface of the earth, all sensible error due to this cause might be avoided by the use of a sufficiently long pendulum. It is, however, a matter of experience that even very long pendulums when hung from the roofs or walls of buildings do acquire a swing often of great amplitude during earthquake shocks. This is no doubt due to the fact that their supports are neither sufficiently free to avoid being thrown into oscillation nor sufficiently rigid to partake simply of the motion of the earth itself.

In the instrument now to be described the pendulum is of great length, and it is supported by a very strong and stiff wooden framework, securely founded in the earth, and entirely disconnected from the building in which it is placed, so as to be uninfluenced by wind, unequal heating by the sun's rays, or other causes.

By making the pendulum long, its supporting framework stiff, and the recording indices exceedingly mobile, it has been attempted to reduce to the smallest possible amount the causes of disturbance just mentioned. As, however, it is impossible to secure that the bob shall remain absolutely at rest during a shock, this seismograph has been designed so that any small swing acquired by the bob will be distinctly shown in the diagrams and be easily separable from the earthquake motion proper. With this view the pendulum has been made twenty-one feet long, so that its natural period of (complete) oscillation is very nearly five seconds. This period is probably much longer than is needed to prevent the period of the pendulum from agreeing with that of the motion of the point of suspension, but it has the advantage that, if the pendulum acquire a swing during an earthquake, its motion will produce a curve of great wave-length in the record, and on this the actual earthquake motions will be superposed in short waves which can be distinguished without difficulty from the long wave due to the swing, and have their amplitudes and

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The bob of the pendulum is of the form shown in figures 1 and 2. It is a cast iron ring $16\frac{1}{2}$ inches in internal diameter, $20\frac{1}{2}$ inches in external diameter and 2 inches deep. It is crossed at one diameter by an iron bar at the middle of which, and close to the centre of gravity of the ring, the indicating levers are applied. The connection with them is made by means of two brass tubes a a' screwed into the iron bar, and into which fit very accurately without sensible friction or clearance the two spherical heads of the levers. These are seen in Fig. 3 and 4 (which give views of the recording apparatus) and are lettered b b'.

Each lever consists of a short upright piece, at the top of which is the spherical end fitting into the tube, and a long horizontal pointer (c c') made by beating out a brass wire flat, so as to be very rigid to resist bending in the direction in which the lever moves, but very flexible at right angles to that direction. The two parts b and c are connected to each other, and attached to the fixed support, by means of a gimbal joint d d'. The effect of this joint is that if one of the levers (say b) is moved in the plane through it and its pointer (c) it will carry the pointer with it, as if the two were rigidly connected; whereas, if b is moved at right angles to that plane, the pointer c will remain at rest, the short arm b revolving about the inner joint of the gimbals. Hence each pointer is affected only by motion in its own direction or opposite to that, but remains wholly unaffected by motion transverse to itself. Each, therefore, registers one of the components of the horizontal motion resolved along c and c' as axes. Fig. 3 gives a complete plan of the recording apparatus. From it and from Fig. 4 the construction of the gimbal joints will be apparent as well as the mode of their attachment to the fixed base of the instrument. The pointers c c' are five times as long as the upright parts b b' of the levers, and the motion of the earth is therefore magnified in record in this ratio.

The points of the levers c c' press very lightly against smoked glass plates e e', which adhere to brass bosses on the

axles $f f'$. These axles carry two small pinions gearing into the teeth of the horizontal wheel g which is made to revolve uniformly and continuously by clockwork, to which it is connected by a band working in the V pulley h.

Figs. 4 and 5 are both only partial views of the instrument, certain parts having been omitted in each case for the sake of clearness. Fig. 4 shows the arrangement of the indicating levers with their gimbal joint supports, and the tubes $a\ a'$ above them. Fig. 5 shows the contrivance used to carry and drive the glass plates $e\ e'$, against which the points of the indicators press, but the levers themselves are there left out.

The axles $f f'$ which carry the glass plates are supported on brass frames capable of sliding in the direction of the length of these axles, and which can be moved backwards and forwards by the thumb-screws $i\ i'$, by means of screws working in the nuts $j\ j'$ fixed to the frames which carry the axles $f f'$. These frames are supported like the slide rest of a lathe, so as to have no freedom of motion except that just mentioned. The object of providing a means of which the axles $f f'$ can be drawn out or in is that the plates can thereby be removed from or brought into contact with the pointers at will. Thus when the instrument is first set up the plates may be kept out of contact with the pointers until the disturbed pendulum has had time to come to rest; also after the record of an earthquake has been obtained they may be put out of contact and then withdrawn without difficulty by unscrewing $k\ k'$ and taking the axles $f f'$ bodily out of their bearings. The pinions on these axles are of such length that they will remain in gear with the wheel g throughout a considerable range of positions of $f f'$. The plates can thus be advanced or withdrawn, so as to press with any required force against the recording levers. Adjustments are provided by means of the bolts and nuts $l\ l'$, by which the axles of the levers may be set exactly perpendicular to the planes of the plates, and the height of the levers be varied at will.

The recording apparatus stands on the top of a timber post 12 inches square (see Fig. 1) firmly driven into the ground and cut off short a few inches above the surface. The

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ON A SEISMOMETER AND A TORSION PENDULUM SEISMOGRAPH.

By THOMAS GRAY, B.Sc.

(Read May 24th, 1880.)

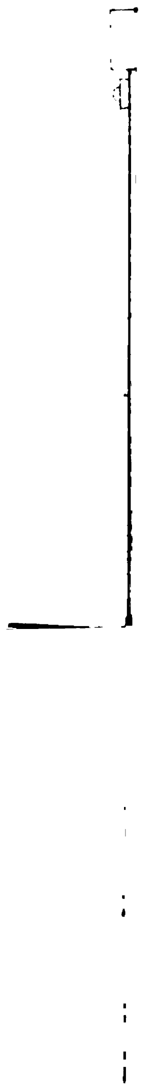
I.—The Seismometer.

The machine which I have called a seismometer is represented in figure I.

The principal part of the instrument is a pendulum with a heavy bob, the centre of inertia of which is connected by means of silk threads with a set of pulleys designed to show, by the aid of indices, the relative motion of the earth and pendulum bob on a magnified scale. The distinctive features are the mode of suspending the pendulum and the arrangement of the pulleys and indices for magnifying the motion.

The pendulum P (fig. I.) is suspended from the cross wire W which can be tightened to any desired degree by means of the screws S S. The object of tightening the wire is to obtain as nearly as possible uniformity in the indications of different machines of the same type. In practice the adjustment can be made either by tuning the wire to a certain pitch and afterwards hanging on the weight, or by counting the number of vertical vibrations made by the weight in a certain time, after it is hung on.

The mode of suspension just described is adopted for the purpose of giving the point of suspension a certain amount of vertical freedom, in consequence of which it can be set in a state of vertical vibration by the earthquake. The maximum amplitude of this vertical vibration is indicated by means of a pointer which turns along with the pulley P, fixed to the frame of the instrument. This pulley is turned by a



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silk thread attached to a rigid rod which rests with one end in contact with the top surface of the pendulum bob.

Three horizontal components of the earth's motion are indicated in a similar manner, by means of pointers turning along with three pulleys *P*, placed at equal distances apart, on the circumference of a circle having its centre in the axis of the pendulum. These pulleys are turned by means of silk threads attached at one end to the pendulum bob, near its centre of inertia, and at the other end to the circumference of the pulleys.

The advantages claimed for the pulley and index arrangement for multiplication are, ease of adjustment, constancy in the multiplying power and, in consequence of the silk thread connection, absence of shock at the first sudden movement. The multiplication can be made 30 or 40 with this arrangement without introducing inconvenient resistance to the motion of the pulleys. Practically, the whole resistance to motion is the small amount of friction on the bearings of the pulleys necessary to retain them in their deflected positions after the shock. The sensibility of the instrument may be doubled and the effect of friction rendered more definite by placing a spring like the hair spring of a watch on the pulleys and then allowing the point of the index to mark on a smoked glass plate.

I indicate *three* horizontal components of the motion for two reasons, namely, that this arrangement gives greater symmetry to the forces acting on the pendulum, and that two components are generally insufficient to give the direction. When two components of the motion only are known the direction of shock may have been along either diagonal of a parallelogram described on these two components at adjacent sides. If three components are given the problem becomes determinate, and we have an obvious geometrical construction for the direction and amplitude of the motion.

The difficulty as to direction, just indicated, may be avoided if the pendulum is made, by means of a pencil or sharp point, to give a direct register of its actual motion on a suitable plate placed under the bob, as shown at *R* in fig. I.

Such a register, although in general somewhat indefinite, would be sufficient to enable the observer to decide between the two diagonals of a parallelogram.

The machine I have described was suggested by me some time ago to Professor Milne as likely to prove sufficiently accurate, easily managed, cheap and portable, to render it suitable for the purpose of taking simultaneous observations at a series of stations distributed over the Yedo plane. In order to make the instrument easily transported the frame carrying it has been made as small as possible, probably at the expense of a certain amount of accuracy in the amplitude indications.

The machine is only expected to give approximately the horizontal movement at any place, perhaps it may not give even approximately the vertical movement. What is wanted is a comparison of the horizontal and vertical movement at different places, during the same earthquake, and as nearly as possible the absolute horizontal direction. From such a set of observations the position on the earth's surface directly over the source may be approximately determined. Again the distance of this position from a series of stations taken along with the relative vertical movement will, on the assumption of a homogeneous earth, be sufficient to give the depth. It is probably too much to assume the earth homogeneous over any very great area, but it must be remembered that a similar assumption runs through the deductions made from an absolute determination of the vertical movement. Other deductions such as changes in the nature of the strata causing differences in the angle of emergence can be got from comparative as well as from absolute observations. The results obtained by these machines can of course be rendered absolute by comparison with another instrument giving absolute indications, if such can be found.

I have stated that I only expect my machine to give *comparative* indications and that only for the *same* earthquake. I made the statement in this form because I doubt very much whether pendulum machines can be relied on for comparative indications of the motions in different earthquakes. All

pendulum machines are subject to error, sometimes considerably due to the forced oscillations of the bob, caused by the motion of the point of suspension. This error can only be the same for different earthquakes on the assumption of similar periodicity and duration in different cases. From my own observation I don't think this is a tenable assumption.

An indication of the probable error due to forced oscillations may be obtained in the following manner.

Suppose a pendulum freely suspended in space has its point of suspension suddenly displaced and then set into a state of simple harmonic oscillation :—

Let a=amplitude of this oscillation.

T'=period „ „

l=length of pendulum.

T=period „

u=angular displacement of the axis of the pendulum from its equilibrium position at any instant.

p=ratio of circumference of a circle to its diameter.

$$n=\frac{2p}{T} \text{ and } n^1=\frac{2p}{T^1}$$

Then the equation to the motion of the pendulum is

$$\frac{d^2u}{dt^2}+n^2u=\frac{a}{l}n^2\cos n^1t$$

The solution for the case considered is

$$u=\frac{a}{l}\;\frac{n^2\cos n^1t+n^{1\,2}\cos nt}{n^{1\,2}-n^2}$$

If besides we assume that the bob experiences frictional resistance to its motion, due to levers or other registering apparatus, we have for the equation of motion

$$\frac{d^2u}{dt^2}+f\frac{du}{dt}+n^2u=\frac{a}{l}\,n^2\cos n^1t$$

The proper integral of the equation in this case is

$$u=\frac{a}{l}\;\frac{(n^2\cos n^1t+l)}{\sqrt{(n^2-n^{1\,2})^2+n^{1\,2}f^2}}$$

where $l=tan^{-1}\,\dfrac{n^1f}{n^{1\,2}-n^2}$

If $tan^{-1}\dfrac{n^1f}{n^{1\,2}-n^2}$ differs from $2p$ the equation shows a periodic oscillation of the pendulum in unison with the earthquake *but differing in phase.* This at once shows the fallacy

of assuming that the ripples on a moving plate are not affected by oscillations of the point of suspension.

A full discussion of the consequences of these equations would be out of place in this paper; and I therefore leave each one to study them for himself.

II.—The Torsion-pendulum Seismograph.

The chief feature of this machine is the use of a torsion-pendulum to furnish at the same time both an approximately steady point, and a moving body on which the motions of the earth may be recorded.

The pendulum consists of a pianoforte wire about three feet in length, carrying at its lower end a heavy ring of lead *W*. The weight and diameter of this lead ring are so adjusted that the period of torsional vibration of the pendulum is more than double the duration of an ordinary earthquake shock. The mode of suspension adopted for the pendulum is shown at *A*, fig. I. and II., *R R* are two steel rods, meeting in a curved joint at *A*, resting at *K K* on knife edges, and held in a horizontal position by two springs *S S*. The ends of the rods *R R* are so formed that a considerable motion of the point *A* produces only a very small increase in the force exerted by the springs. The pendulum has thus a long vertical period and is therefore capable of showing approximately the actual movement of that part of the earth's surface on which the frame rests.

The knife edges *K K*, and springs *S S*, are fixed to a table *T*, which rests on three hard balls *B*, placed between hard metal plates. The object of this table is to obtain, as nearly as possible, a steady point for the suspension, this being, in my opinion, one of the first things to be looked for in connection with pendulum machines. The principle of obtaining a steady body by resting it in a state of neutral equilibrium on the top of balls, was, so far as I am aware, first used in connection with earthquake measurements by Dr. Verbeck. The principle, if properly applied, is far better than that of a pendulum, no matter how long, rigidly attached to a body resting on the earth's surface. I have introduced the principle into this instrument more as a matter of experiment than

prongs of the forks F. By causing the points of the levers to

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as an essential element of the machine, but I hope to point out one or two interesting modifications of the machine in which it would figure as an essential part. In this machine the balls can be removed at any time, and the top of the pendulum fixed to the framework. By making experiments with this and other machines, on artificially produced earthquakes, I hope to obtain some valuable information on the necessary elements of an earthquake machine.

The remaining portions of the machine will be easily understood from the following description of how it records the earthquake shock.

A disk of wood *D* rests on three levelling screws *L*, fixed in the ring of the pendulum, and carries a plate of smoked glass. Through a slit in the glass plate, used for allowing it to slide past the rod of the pendulum, a small pin rises, which when the bob of the pendulum is twisted through 180° can be caught by a catch *C*. This catch consists of a weak spring, held bent by the friction between it and the pin. The catch *C* rests in contact with one of the levers attached to the pulley *P* and is released immediately this begins to move, if not previously released by the earthquake itself taking off the friction between it and the pin.

The bob of the pendulum then begins to move slowly round, with a velocity which is at any point of its path, calculable from the well known laws of simple harmonic motion. During this motion of the bob, two levers *l l*, fixed to pulleys *p p*, are turned by means of silk threads attached to the axis of the pendulum, and write simultaneously two rectangular components of the earth's motion on the same radius of the bob. The threads are prevented from winding round the rod of the pendulum by attaching them to a small ring *t*, which turns freely along with them. The pulleys are turned in one direction by the motion of the earth and pulley, relative to the pendulum bob, and in the other direction by the torsion of fine wires which form the axis of the pulleys. The wires forming the axes of the pulleys, shown clearly in the diagram, are kept taut by means of threads attached to the lower prongs of the forks *F*. By causing the points of the levers to

write on the same radius of the bob it is easy to tell whether at any particular instant the pulleys were both turning in the same or in opposite directions. This may perhaps serve to show whether there is a distinct change in the direction of shock during the earthquake, even although that change is such as to give the same relative value for the components of the motion. Arrangement is also made for marking the motion of the bob on a plate beneath it, so that a check can always be obtained on the indication of the components.

The vertical component of the motion is recorded, in a similar manner to that just described, on the edge of the bob, by means of a pulley and crank lever P which is turned by a thread attached to the end of a rod or wire passing down vertically from the rod to which the pendulum is suspended. The crank lever is hinged at H, and the vertical arm made to press against the edge of the weight by means of a weak spring S.

This machine, then, aims at giving both the horizontal and vertical movement in so far as these can be given by means of a pendulum. It also attempts to give the number of vibrations, their periodic times, and their amplitudes. The duration of the shock, after it has reached a sufficient force to start the apparatus, and the intensity previous to that, will also be given. The calculation of the interval between different shocks in the earthquake is very easy when the period of torsional vibration of the pendulum is known. The indications will be independent of the ordinary pendulum period of the pendulum' provided the amplitude of swing is not so great as to drive the levers off the plate.

I have stated above that the duration of the shock, after it has reached a certain intensity will be given. It is easy however to introduce an arrangement which will make this instrument record as much of the earthquake as can be done by means of any clock work machine with the same magnification. All that is necessary is to introduce another lever into the instrument so arranged as to turn at right angles to the levers already described. If the end of this lever be made to move under the point of one of the levers formerly described the latter lever will record a series of figures like

lemniscates of gradually increasing amplitude on the former. The number of these can be readily counted and the period of each obtained from those which immediately follow the starting of the pendulum.

An obvious modification of the machine just described would be got by sacrificing the vertical component, and substituting for he twisted suspending wire a flat spiral spring. We would in this case get an arrangement exactly similar to that which we would have, if we laid a watch on the table *T*, and wrote the earth's movement on the balance wheel. To perform all the operations for the horizontal movements which my pendulum performs the watch mechanism is of course unnecessary, but the illustration suggests many simple applications in which the use of the mechanism might form a principle part. It would be easy for instance so to modify our mantle piece clocks that they would serve both as time keepers and as seismographs capable not only of recording the different motions of the earthquake, but also the exact hour, minute, and second, at which they occurred. If we could only persuade people to use clocks of this class, and time them properly, we should in a very short time know more of the earthquakes of this country than is known of the earthquakes of any other country at the present time.

ON A DETERMINATION OF THE ACCELERATION DUE TO THE FORCE OF GRAVITY AT TOKIO.

T. C. Mendenhall.

(*Abstract.*)

This determination was made by means of a pendulum vibrating in the physical laboratory of the University of Tokio. A number of experiments were made with a reversible pendulum in the early part of the year 1880, but as the laboratory at that time possessed no means of measuring the distance between the knife-edges with sufficient accuracy, no attempt was made to perfect this method.

In May a series of experiments was undertaken with what is commonly called a "Borda's pendulum" made by Salleron of Paris. It consisted essentially of a small brass sphere suspended upon knife edges by means of a thin platinum wire. There was also provided by the same maker an arrangement for measuring the length of the pendulum within the one-hundredth of a millimetre. The determination of the time of vibration was made by means of a chronograph and a break-circuit chronometer. The pendulum was made to record on the sheet of the chronograph a single beat at the begining of a series of vibrations and again at the end. In this way the number of seconds and the fraction of a second in which the pendulum completed a given number of vibrations was ascertained without introducing objectionable resistance and with a much greater degree of precision, for the same length of time, than is possible by means of the ordinary method of coincidences. All parts of the pendulum were weighed and measured and the results were reduced and

corrected in the usual manner, allowance being made for the air dragged with the pendulum while in motion.

The results of a number of series of observations were given, agreeing well with each other, the mean of all giving for the value of the force of gravity at Tokio.

$$g=9.7984$$

Brief reference was made to a previous determination of the same constant, by Messrs. Ayrton and Perry, at the Imperial College of Engineering. (*Philosophical Magazine*, April, 1880.)

The method used was criticised, and many errors made in the reduction of the results were pointed out.

ON A NEW SEISMOMETER.

BY DR. G. WAGENER, KIOTO, JAPAN: JUNE 1880. WITH A SUMMARY OF OBSERVATIONS BY E. KNIPPING.

Reprinted from the "Japan Gazette" of July 10th, 1880.

This new seismometer having been in practical use since November 1878, and the observations showing apparently reliable and satisfactory results, it now seems opportune to give a full description of this instrument.—Several seismometrical contrivances set up in Japan, in conformity with Robert Mallet's instructions in the *Manual of Scientific Enquiry*, London, 1871, or those contained in the *Anleitung zu wissenschaftlichen Beobachtungen auf Reisen*, Berlin 1875, having given no satisfaction (see Mr. Knipping's paper in the 14th vol. of the *Mittheilungen der deutschen Gesellschaft fuer Ostasien*, April 1878), it was intended to make an instrument suitable not only to mark the time of an isolated earthquake shock, or of each one of a succession of shocks, but also, if possible, to give some information more approximate and more complete than that which until now had been obtained with instruments intended to measure the extent of the motion of the earth. The principle was explained in a paper read in June 1878, and published in August 1878, by the above named *Deutsche Gesellschaft etc.* in Tokio, who decided to have the instrument made at the expense of the Society. Mr. Knipping undertook to superintend the manufacturing of the apparatus and to make the observations.

Like several other instruments, this new seismometer is composed in one part of a suspended pendulum; and it will be necessary to explain how it differs from the other

instruments in principle and in shape, these explanations being sustained and completed by an experience of nearly two years.

Robert Mallet, in his 4th Report, British Association 1858, describes as the "oldest, probably, of seismometers" a pendulum, free to move in any direction" with a stile below the bob and a concave dish placed underneath, covered with a stratum of fine dry sand. "It was supposed, he says, that the stile would mark a right line when seen in a plane vertical to the sand-bed, and in the direction of the shock." Then Mallet describes several other seismometers and finally exposes his views on pendula in general, which, he says, "have disadvantages both theoretical and practical or constructive which render their indications inaccurate." In order to account for this latter draw back, Mallet explains the well known principle, that a pendulum can easily be made to swing by giving to the point of suspension, impulses in intervals corresponding to the time of oscillation of the pendulum or to a multiple of it; and that on the contrary the pendulum remains sensibly stationary when this is not the case. From this he concludes that the indication of the instrument will either be in excess of the horizontal component of the wave, or much less than it; but he does not propose that the oscillations of a pendulum should altogether be rejected as a means for indication in the case of an earthquake. Writing thirteen years afterwards (see Chapter on Seismology, in the *Manual of Scientific Enquiry*, 4th edition, London, 1871, page 311), Robert Mallet only recommends one solid pendulum which "by the shock, is caused to oscillate in any direction." In the whole of his 4th report, 1858, there appears to be not one single passage in which Mallet, who is plain enough on every thing, refers to an apparatus composed of a suspended weight and a suitable indicator to move against this weight in the moment it is still inert. But, of course, he is well aware, that a pendulum remains behind in the first moment of a shock, and knows also, under which conditions it will swing or not swing.—In later years, (see Le Conte's *Geology*, New York, 1878), Prof. Cavalleri

appears to have proposed an instrument, which, according to the description, is nothing else—however with a slight modification—but a new edition of what Mallet calls the "oldest, probably, of seismometers." But it is said in the description, that the "pendulum tends to retain its position." Whether for the sake of this theoretical supposition, which is scarcely different from Mallet's statement that the "pendulum remains behind in the first moment," and his other explanations, Cavalleri's instrument has been free of all the disadvantages, which, according to Mallet, are common to all pendula, I do not know, nor have I been able to ascertain what sort of observations have been made with it. From 1877 to 1878, Mr. Verbeck in Tokio, not being satisfied with the results obtained through an oscillating pendulum, as he wrote himself to the author of this paper, put up another instrument composed of a heavy planed piece of wood with a slightly ballasted pencil in the middle, and resting through four crystal balls upon a polished marble slab. The piece of wood remaining inert during the shock, the pencil made certain marks upon a sheet of paper placed underneath. These marks are only very short strokes, and may well be considered as some more evidences of what results from Mr. Knipping's observations with the new seismometer, viz.: that the extent of motion of the earth, during an average shock, amounts to a few millimeters only.

Robert Mallet has pointed out a great many disadvantages or difficulties connected with pendula. If in spite of these objections, a new trial was made with a pendulum, it was for the reason, that, in case most of the drawbacks could be overcome, such an apparatus would have the great advantage of extreme simplicity. I may state at once, that the observations of nearly two years furnish sufficient evidence that the experiment has been successful to a very great extent. But before giving a full description of the new instrument, a few theoretical remarks will not be out of place.

If the point of suspension of a pendulum being at rest, receives an impulse, the bob of the pendulum remains behind

in the first moment. It is this inertia of the first moment which the new instrument makes use of for indication. This remaining behind in the first moment takes place in all cases, whether the pendulum is long or short, whether it depends from a rigid or from a shaky scaffolding. Thus, a suitable indicator moving against the inert bob, is always sure to mark the *exact time* of the *first* shock. If the pendulum is not too short, so as to be dragged along before the end of the first impulse, the indicator will also allow to calculate from the indication the *extent of the horizontal motion; but only if we are certain that any following oscillations of the pendulum will not alter this first indication.* This already involves a considerable difficulty, chiefly if there is no registoring apparatus, like the phonograph, which might render it possible to distinguish the tracing of a shock from the tracing of the oscillations of the pendulum. In general, it is easily understood, that the indication of nothing but one first impulse during an earthquake does not involve very great difficulties. But they are considerable, as soon as the problem is to mark all the different impulses during an earthquake with equal correctness. The most perfect seismometer would be obtained, if a body could be made permamently inert during an earthquake; but this being an ideal, we most likely must be content with a body, which at each new shock, is *likely* to be in the same condition as when at rest.

To examine whether this is possible or not, we have to minutely consider how a pendulum is influenced by the various forms of an earthquake and the phenomena depending on it. The well known principle as above mentioned, shows that it is not advisable to use a long pendulum pending from the roof of a house or any other point subject to vaccillations in consequence of the shock. These being slow and not isochronous, they are most likely and even certain to affect a pendulum, whatever may be its length. The principle also makes it evident that, the point of suspension being upon a rigid scaffolding not liable to vacillations, it is sufficient to give the pendulum a certain length in order to

be almost sure that it will not be affected by eventual periodic oscillations of the soil which always will be quicker than the time of oscillation of the pendulum. Indeed, it can be shown with a very simple apparatus composed of a horizontal bar of wood, with a slit in the middle to permit a string to pass through, one end of which is fastened to a block of wood, the other end carrying a weight—that the point of suspension can be moved to and fro, in excursions of several inches, without producing any noticeable swinging of the weight. These were the ideas explained in the paper of June 1878, and it was only said (see page 221 and page 223) that nevertheless the indications might be obscured by oscillations, but that it was superfluous to describe improvements before having seen that there really were such oscillations; that in general it was to be seen, how the instruments would work, that even a failure would teach something, and that there was no other way of information but the experiment. Its particular construction had only a general purpose to prevent disturbing oscillations, and the first record published in May 1879 stated that it had worked to entire satisfaction. But the reason of its good working and the difficulties of pendulum seismometers in general can be better explained now, after an experience of nearly two years and after having heard of other pendula having been swinging, than this has been done in the first paper.

The above principle referring to the influence of periodic impulses upon a pendulum, takes into account no other element but a periodic and constant interval of time between two successive impulses, and involves—for the case that no swinging shall take place—the supposition that the effect produced in one direction is equal to that in the opposite direction. With the above described pendulum apparatus, it can easily be shown that, if the point of suspension is moved to and fro with equal excursions on both sides of the starting point, the pendulum does not swing, even in spite of considerable excursions. The same—or only a very slight swinging—takes also place when the excursions decrease very gradually on both sides of the point of rest, until the

point of suspension is brought to rest again. But we can not suppose that at the time of an earthquake, the earth oscillates with such regularity. In the *Anleitungen zu wissenschaftlichen Beobachtungen auf Reisen*, Berlin 1875, page 311, K. von Seebach says: "Only during very weak earthquakes, the wave-like motion appears as a uniform tremor; the general case is that in this motion one or several more violent oscillations can be distinguished, which are then designated as separate shocks."—Anybody who ever has made the experience of an earthquake, will agree with this view of its features. If we now repeat the pendulum experiment under conditions similar to this description of an earthquake, we will find that the pendulum is easily made to swing. With a bodily mass so discontinuous and heterogeneous, and of so little elasticity as the soil, we may even admit, that at the time of a shock every particle of the soil is thrown out of its position of rest, but that in coming back it very little depasses this former position, and comes to rest again after a few rapidly vanishing oscillations, differring in this entirely from the different points of a highly elastic body. It happens thus that the effect of the first impulse, that which we call the shock, by far dominates the effect of the following oscillations. We therefore may compare the total of the effect to that produced by a sudden motion forwards and then backwards to the point of rest. If we make this experiment with the point of suspension of a pendulum, the latter only receives the impulse at the forward motion, but no impulse when the point of suspension comes back to its former position. The consequence is that the pendulum will swing, more or less, the degree of swinging depending on the extent and velocity of the shock, on the length and the weight of the pendulum, and on some minor circumstances.

This particular feature of an earthquake, that is some more or less of oscillations of the soil intermixed with sudden and much stronger shocks, being the usual case, it is clear, from the above explanations, that the principle of the influence of regular periodic oscillations of the point of suspen-

sion upon a pendulum is, after all, only of minor importance. It has been said (see *Japan Gazette*, May 1st) that "it is a well known principle that the bob of a long pendulum may be assumed to be sensibly stationary during most shocks, since the periodic time of a shock is probably far less than the natural period of oscillation of the pendulum," and further that the "pendulum method is widely trusted by seismologists." It is not said what method or what instruments are meant; but it can be safely asserted that the said principle alone does not involve the most important feature of an earthquake, and well may "grave doubts" be expressed (see same place) as to the "supposed steady pendulum really being steady." However it seems, as will be shown, quite possible, that some pendulum method is sufficiently trustworthy for time and approximate intensity. And there is no other means to be tolerably sure of this but a connected series of observations or a registering apparatus.

It will have been understood from the above explanations that, if the earthquake consisted in regular or nearly regular and isochronous, only gradually decreasing oscillations of the soil, the construction of a seismometer would present no difficulties whatever, after once having adopted the principle to make use of the inertia of a pendulum instead of the oscillations. But in order to make a practical instrument, it is also necessary to render the indications unaffected by pendulum oscillations after a shock, even in the case that several shocks should follow one another at short intervals. This appears to be realised by the seismometer to be described hereafter; and I think that in presence of the facts and evidences gathered after an experience of nearly two years with the same unaltered instrument, it is not too much to give of this apparatus the following definition:—

The new seismometer makes use, for the indication of time, horizontal intensity and direction, of the perfectly certain—under all conditions perfectly certain inertia of a pendulum in the first moment. All these indications—even in the absence of a moving registering apparatus, the indications of intensity and direction being those of the most violent shock during an earth-

quake—are not altered by the pendulum oscillating in consequence of an impulse, whatever may have been the violence of this shock. And further, if the pendulum does oscillate, it comes to rest again after a few seconds, even if the shock has been as severe as the most violent shock that has been experienced in Tokio in later years, so that the instrument is almost certain to indicate every single shock of an earthquake under the same conditions of rest as the first one.

The correct and distinct indication of the time of each shock is undoubtedly the most important query of seismology. All seismologists agree in this, and amongst observers in Japan, I may mention Mr. Knipping, who began his observations in 1874 with different instruments suggested by Robert Mallet and others. In his paper on earthquakes in Japan (see Vol. 14 of the *Mittheilungen der deutschen Gesellschaft etc.* April 1878, page 118), he says: "The final result "of the experience acquired in Tokio with the above said "seismometers, has been so unsatisfactory that they must "be entirely rejected, even in countries subject to tolerably "strong earthquakes. Indications of time, as exact as pos-"sible, in places connected by telegraphic lines, as K. von "Seebach has proposed them showing also their application "to determining several elements of the earthquake-wave, "seem to be the only right thing to get."

In his report on the Meteorology of Tokio, for 1879, page 42, Professor Mendenhall says: "I regard it as highly "desirable to erect some simple indicator, which may not be "liable to get out of order, and which in connection with "some of the time-cylinders in use, or to be used in the "observatory, may indicate the time of the shock, certainly "or with the smallest chance of failure. If we shall succeed "in this one determination with unfailing certainty, the "result will be a contribution of no small value and well "worth the trouble and expense which will be rendered "necessary."

It was Mr. Knipping's paper, that induced me to try the construction of some more practical instrument than those which, in his opinion, had proved a complete failure.

Only I gave a little more extension to the problem, explaining that for several reasons, besides the absolutely indispensible element of time, it would also be desirable to have an indication of intensity of more approximate correctness than hitherto had been obtained with seismometers. The different instruments for time, intensity and direction, as well as the object of a moving registering apparatus were described in vol. 15 of the Transactions of the German Asiatic Society, August 1878. Since the first object was to be quite sure of the good working of the various instruments, it was decided to dispense for a time with the registering apparatus which has been ordered only a few months ago and is not quite ready yet. The apparatus for time and horizontal intensity is at work since Nov. 1878, and apparently in so satisfactory a manner that there were no reasons for making alterations. It is the same which was sketched and described in the paper published in August 1878, with the sole difference that the indicating pendulum rests upon a sphere instead of a point as was said in the description. Experiments have shown that, in putting this apparatus into the position which it must have had at the end of the strong shock of December 3rd, 1879, and abandoning it to itself, it comes to complete rest again in not quite four seconds. During the earthquake of February 1880, the thread leading to the index-wheel was broken, but for some accident, it could be assumed with good probability that the extent of the motion of the soil had been five times as much as in December 1879. Giving the apparatus the position corresponding to this assumption, it comes to rest in 15 seconds. In these experiments, without an earthquake, the apparatus, as will be understood by the description, is in a condition much more favourable to oscillations than in the case of an earthquake. We therefore may fairly assume that after a strong shock, the apparatus is again at rest in a much shorter time. It must be observed that the construction of the apparatus allows to still reduce these figures; but it is quite unnecessary to do so before the registering apparatus is ready. However, they are sufficient to make

it plain that in most cases, when several shocks can be noticed in one earthquake, the apparatus will indicate every one of them, starting from the same condition of rest as when the first shock occurred.

As to intensity, I also shall refer to facts in order to show that the indication of the extent of motion of the earth, at the time of a shock, has never been altered—or not sensibly altered—by the following oscillations of the pendulum Before evidencing this by figures, it must be observed that the indications of intensity are not figures eliminated as to say out of a sinuous line traced upon a revolving registering apparatus, but are figures directly and distinctly shown by the index. From November 1878 until December 1879, 24 earthquake-shocks have been indicated: and the different values of the extent of motion, the instrument always indicating that of the most violent shock during an earthquake, are comprised between 0^{mm} ($0{,}03^{mm}$ were actually indicated) and $4{,}3^{mm}$. These figures are sufficient to show that eventual oscillations of the pendulum can only have had a very small, quite insignificant influence, or more likely none at all. Thus the above figures resulting from the indication in the first moment when the pendulum is still at rest, must be considered as very approximately correct. They also corroborate the other statement, that the oscillations, being only of a very small excursion, come to rest very soon. The reason why the new seismometer is so little or rather not at all put into motion by the impulse of an earthquake-shock, will be fully explained in giving the description of the instrument. The apparatus for determining the azimuth of the strongest shock being of the same construction as the other one, the above statement referring to the almost complete absence of disturbing oscillations, applies also to this instrument.

It has been said that the registering apparatus, indicating the time and intensity of each separate shock during an earthquake, is not ready yet; and it may also be observed that its construction has been reduced to the utmost simplicity, because the main object was to first test the working

of the whole system before ordering a more expensive instrument. In the shape which is intended, it will show whether some more improvements referring to the steadiness of the weight are necessary or not and there is still a large margin left for improvements. They will be easy enough, and in case of need, the point suspension of the pendulum will be arranged in such a way as to remain behind like the bob itself, and to retake its position after a few vibrations which in no way or scarcely can affect the suspended weight, provided only they are quicker than the time of oscillation of the pendulum.

To determine the azimuths of all the different shocks during an earthquake, is not without importance since it may happen, that for some deflection of the wave, or because there are more than one centre, they are not all in the same direction. Such an apparatus will be made after having finished the time registering instrument.

The vertical intensity of a shock is measured through a buoy suspended in water and forming the inert body. It is very likely that a similar arrangement has already been proposed by other people.

Amongst all the instruments to be described hereafter, the most important one undoubtedly is that for time and intensity; and we may be allowed to point out some of its advantages:

It is sufficiently sensitive, but also solid enough to resist strong shocks without getting out of order;

The connection between the weight and the indicator is permanent, and consequently independent of the observer's carelessness or attention;

The indication of intensity is in no case sensibly altered by following oscillations of the pendulum;

After a shock, even a very violent shock, the apparatus comes back to complete rest within a few seconds;

The instrument is plainly comprehensible to any body, and avoids electric or other arrangements which it would require a certain scientific training to keep in order;

The instrument is not expensive;

It is transportable and requires only a very small space any where under a shelter.

Finally after all these explanations, the reader is referred to the summary of observations (see hereafter) made by Mr. Knipping, to whom the writer of this paper is extremely indebted for the untiring perseverance, he has so kindly given proofs of, in superintending the construction of the instruments and in making the observations. The results undoubtedly have a most satisfactory appearance; and the task will now be to ascertain the practical limit of perfection which can be attained.

Description of the apparatus for time and horizontal intensity.

The scaffolding is in the shape of a four-sided pyramid solidly framed and put upon the ground, in such a way that it is bound to follow its motion. From this scaffolding, an iron ball weighing 40 to 50 lbs., is suspended by a thick bundle of untwisted silk-threads 3 feet long. At this same scaffolding, underneath the heavy weight, is fixed a solid iron bar carrying the indicating part of the instrument This consists of a stiff pendulum, suspended by a point below its upper end. The suspension must be such that by the slightest as well as by the most violent shocks or excursions of the soil the pendulum should be carried forwards and backwards with equal sensitiveness and without getting out of order. For this purpose the support of the pendulum is a metallic sphere of $\frac{3}{8}$ of an inch diameter, and the pendulum rests upon this sphere with a smooth plate forming the top of a hollow cylinder. The inner diameter of this cylinder is exactly equal to the diameter of the sphere so that the pendulum can pivot in all directions upon this sphere, but can not slide. The lower and longer part of the pendulum is fixed at this cylinder through a large vertical brass ring, which allows the iron bar carrying the sphere, to reach underneath the point of suspension. This brass ring does in no way effect the pivoting of the pendulum, since in case the ring should hit against the iron arm, the apparatus will only

give a slight turn on its geometrical longitudinal axis, and continue to pivot. The connection between this pendulum and the heavy weight is established in the same way as the suspension itself. The iron ball forming the weight carries below, a small sphere like the supporting point, and this sphere fits exactly into a hollow cylinder, screwed on the top of the indicating pendulum. It will be easily understood that through this connection, as soon as the supporting point of the indicating pendulum makes the slightest horizontal movement the heavy weight remaining motionless, the indicator is bound to pivot, forwards and backwards, once or repeatedly, exactly as the motion of the point of suspension requires. It is advisable or even necessary to give to the indicating pendulum such a construction, that its centre of gravity is near the point of suspension. This at least was aimed at in the construction of the instrument, which has given, since Nov. 1878, entire satisfaction as to its working qualities. It is evident also that this pendulum must be as light as possible in order not to affect the heavy weight; but it is also evident that this short pendulum has a much shorter time of oscillation than the former one, and that its very weak impulses take place in alternate directions. It is therefore certain that in case oscillations *should* occur, which will always be after the first pivoting, they cannot affect the *indications* of the pendulum. In this first seismometer, since nothing was known concerning the real excursion of the soil during an earthquake, it was considered advisable to make the pendulum long enough to get clearly visible indications and to stop a clock even in cases of very weak shocks. The length of the pendulum from the point of suspension to the lower end is 2 feet, and to the upper end or rather to the center of the small sphere which holds the upper end, is 1 inch. Thus the ratio of the two arms of this vertical lever, is as 24 to 1. A scarcely perceptible motion of the point of suspension produces a considerable motion of the lower end. At this lower end is fastened a flexible silk-thread, which passes through the small hole of a thin porcelain plate immediately underneath. This thread is wound around a light

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indicating

ing pendulum is in exact proportion to the violence of the shock. It happens thus that at the end of the shock, both pendula have a moment of perfect rest with no tendency

to move in any direction. The now following motion only is due to the circumstance of their being out of their position of equilibrium, and depends on gravitation alone. But as the large pendulum begins to swing, its point of suspension come back to meet its motion; besides, it has the impediment of the indicating pendulum, which remains always connected with the large one. The result is that both pendula exercise such a reaction one upon the other, that the swinging can not reach far enough to alter the indication of the first moment. The hitherto explained checking action of the indicating pendulum can be regulated to satisfaction with the help of a small sliding weight.

Apparatus for direction.

Like the first apparatus, it consists of the heavy weight and a pendulum of identical construction. But this latter carries at the height of the point of suspension, eight light horizontal arms, 9 inches long, connected with each other at their ends through a light hoop. Above this hoop and upon a sort a platform, are eight wheels like that in the former apparatus, with indicating needles. A thread would around each of these wheels is connected with the end of the corresponding arm of the pendulum, and in such a way, that, when all is at rest, all these threads are tense and the needles upon zero. When a shock accurs, the indicator will pivot, the plan of the eight arms will be inclined, some of the threads will be pulled, and the needles turned more or less. The wheels are put up so as to force the eight arms into the eight principal directions of the compass, and to keep them there. That point where the greatest pull took place, shows the direction from where the earthquake came; and this indication is *not* affected by slight balancing motions of the eight arms, which may occur because it is not possible to give to the instrument a mathematical precision. When it has to be put in order again, nothing is necessary but to bring the needles back to zero; and as there may be slight changes in the tension of the threads, and the needles not come back exactly to zero, the graduated circles are made

moveable so that the needles can always be turned upon zero.—I dare say, that although this apparatus looks a little complicated on account of the eight wheels, its working can easily be understood by anybody.

If the seismologists will be content with the exact azimuth of the first shock only, it is easy enough to connect the eight arms with the threads in such a way, that in the moment of a shock, all the threads in the raising half of the disk are disconnected, whereas on the dipping half they remain tight. But as soon as this half begins to go up again, they are also disconnected. The consequence is that the needles on the side from where the shock came, remain exactly in the position they had at the end of the shock, whereas upon the opposite half they all remain upon zero. No oscillations of the large pendulum can alter this perfectly correct indication.

Registering apparatus.

Like in the drums used as phonographs, one end of its axis is not a cylinder but a screw, so that each point of the drum when it turns, describes a screw line. A pencil remaining motionless would then mark a screw line upon this drum, or if the pencil moves up and down, it will draw a sinuous line, the sinuousities of which will not fall together. This drum is turned directly by one spiral spring whose axis lyes in the prolongation of the axis of the drum. Since the latter is forced to ascend, no further regulation of the movement is necessary; it will become uniform after a very short time, and if not, it does not matter as will be seen hereafter. When the spring is wound up, the drum is prevented from turning, by a sort of catch. In the moment an earthquake shock occurs, the thread at the end of the indicating pendulum (see former descriptions) pulls a light lever, the catch drops and the drum begins to turn. In order to prevent the short delay resulting from the inertia of the drum, the catch is constructed in such a way, that it helps to start the drum. The same thread pulls a pencil, which, through a combination of two levers with a link well known in mechanics, is forced to make only a rectilinear motion up

and down. The arrangement is made in such a way, that the starting of the drum and the pulling of the pencil through one and the same thread, don't interfere at all with each other. The drum stops by itself after a few revolutions, which may last four or five minutes. The observer, when all is finished, takes the time in the following way. He brings the drum back to its normal position stopping it with the catch. He takes in one hand his pocket watch and in the other the thread of the pendulum. Pulling it now at regular intervals of say 5 seconds, he will start the drum, which will turn exactly as it did before, and the pencil will mark intervals in space corresponding to the regular intervals of time. Provided the drum only turns in the same way as before—and there is no reason to suppose a perceptible difference—it is indifferent whether the drum has had a perfectly uniform motion or not. It would be easy to find the perfectly correct time through interpolation. Now, since an other apparatus has given the moment of the first shock, the diagram of the drum will show the excursion, the moment and the duration of each successive shocks. Any secondary oscillations of the pendulum will most likely be immediately recognised, since their shape can easily be determined through experiment without any earthquake. I may finally add that, in order to help the alternate motion of the pencil, for which its own weight and the weight of the levers might be sufficient, it has been considered useful to fix the end of the thread at a spring, which pulls it down again.

Apparatus for vertical intensity.

This instrument consists of a sort of buoy suspended at a lever, whose fulcrum is rigidly connected with a tub to be filled with water. The lever is counterweighed in such a manner that the buoy, whose specific gravity is a little above one is suspended amidst water. If now the tub is suddenly raised by a vertical motion of the ground, the buoy will not follow immediately and remain behind just as the heavy weight in the other case. Thus it pulls the lever, and the end of this lever, making a very considerable excursion

in relation to the ground and all the things rigidly connected with the ground, can pull a thread and move a needle like the thread of the indicating pendulum in the other instruments.—I may observe here that the buoy may be made as heavy as anybody thinks proper, since it will always be carried by the counterweight upon the lever. But in this case, by the sudden shock, the lever might be strained so as to be bent or broken or the connection with the tub might be damaged. For these and other merely practical reasons, the buoy was not made too heavy. Experience will show which are the best proportions.

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* Summary of Observations, made with Dr. G. Wagener's Seismometer, by E. Knipping.

1. *Maximum horizontal motion of a point of the earth's surface, measured from its position when at rest, November* 1878 *to April* 1880.

Number of earthquakes.	Degrees shown by the instrument.	Corresponding maximum horizontal motion of the ground in millimeters.
10	0° to 5°	0 to 0.15 mm.
7	5 „ 21	0.15 „ 0.5 „
8	21 „ 114	0.5 „ 2.5 „
2	114 „ more	2.5 „ more „

The clock lever is pulled down whenever the instrument marks 3 degrees or more; *i.e.* when the motion of the ground amounts to somewhat more than a mere tremor or to more than 0.1 mm.; but this is not to be considered as the lowest limit, at which the clock can be stopped; in a new instrument there will be no difficulty in reducing the last figure to 0.03 or even less.

The extent of the motion as given by the indicator has always been in perfect accordance with the violence of the shock, as far as this can be estimated by the feeling.

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* For first summary see: *Mittheilungen der Deutschen Gesellschaft etc. Ostasiens*, vol. 17 May 1879; reprinted in *Wochenschrift fuer Astronomie etc.* edited by Dr. Klein, Cologne 1879 page 365 and *Zeitschrift der Oesterreichischen Gesellschaft fuer Meteorologie* Vienna March 1880.

The force, with which the indicator strikes against the weight in heavy earthquakes, or rather the inertia of this weight, may be judged from the fact, that February 22nd 1880, the thread fixed to the indicator, was broken, its length not being calculated for such heavy shocks.

2. *Maximum vertical motion.*

was observed since January 1879, 8 times, but only in 4 cases the angle indicated by this instrument amounted to 1 degree (0.02^{mm}. absolute measure) or more; the greatest value, observed until now, was 0.56^{mm}. February 22nd, this year.

3.—*Direction of shock.*

The instrument showing the direction, whence a shock came, through the dip of the plan, formed by 8 arms around the indicating pendulum, indicated upon the graduated circles (since May 1879.)

3 times a maximum angle between	0 to	5 degrees.
5 „ „ „ „	5 „	100 „
8 „ „ „ „	100 „	more „

The length of an arc of 5 degrees in this instrument is about 7^{mm}. and corresponds to a dip of the plan of 0.4 degrees.

As a sample of the kind of indications of this instrument I give here the figures in degrees for the 8 arms on Dec. 17th, 1879.

Arms	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.
Degrees	5	29	87	123	105	42	0	0

Whence the direction, from which the shock came is found as about S. 25° E.

TRANSACTIONS

OF THE

SEISMOLOGICAL SOCIETY

OF JAPAN.

PART II.

1880.

EARTHQUAKES.

THE EARTHQUAKE IN JAPAN OF FEBRUARY 22ND, 1880.

I.

INTRODUCTION.

THE earthquake which it is my intention to describe is one which for various reasons ought long to be remembered. Many of the inhabitants of Yokohama will associate it with the destruction of roofs and chimneys which it occasioned, whilst others will think of it as a cause which produced an awful shock of sudden terror, and gave a tone to the conversation of several succeeding weeks. The members of the Seismological Society to whom this paper is chiefly addressed, will remember it as the final impulse to the establishment of their society. In many ways this shock was remarkable, and being such, it has a right to be recorded. The greatest fear I have in undertaking the task of making such a record is because the materials which are at my disposal to work with being scanty, the result will not reach what many may perhaps anticipate. The scantiness of records on which to base deductions is, in a country like Japan, an unavoidable necessity. Everywhere the houses are built of wood and generally speaking are so flexible that although at the time of a shock they sway violently from side to side in a manner which would result in utter destruction to a house of brick or stone, when the shock is over, by the stiffness of their joints they return to their original position, and leave no trace which gives us any definite information about the nature of the movement which has been taking place. In a country like Italy, however, where the buildings are of stone, the results are different; and if the shock of which we speak had occurred in such a district, it would, no doubt, have left sufficient

records wherewith to write its history. Again, in a country like Italy, we have many towns in which there are dwelling persons who are more or less accustomed to making scientific observations: places are connected by telegraph and railroads; clocks are numerous, and by their stopping furnish approximately accurate results with regard to time. In all these respects the observational seismologist has opportunities for collecting together information which we could hardly obtain here. What consolation the residents in Yokohama may have received for the losses they have sustained, I am unable to say, but certainly if the houses in which they dwell had not been built our information about this earthquake would have been so small as to be almost valueless.

The history of my endeavours to obtain information about the shock were as follows: At the time of the shock which was about 10 minutes before 1 on the morning of Sunday the 22nd of February 1880, I was asleep. It, however, quickly woke me and by means of my watch, and a lamp which was burning close to my head to enable me to observe the time of earthquake shocks, I obtained very fairly the time of commencement and the duration of the shock. At the time the house was swaying violently from side to side, and even when I thought the motion had finished the distance through which the building was oscillating was so great that I was unable to walk steadily across the floor. Immediately after this I visited two long pendulums which, with various other apparatus, I had been using for making experiments on earthquakes' motion. The respective lengths of these pendulums were about 20 and 30 feet, and at their lower ends one carried a weight of 20 and another of 30 lbs. At the time I saw them which was within a minute after the cessation of the shock, they were swinging violently through a distance of 2 feet. They would have swung farther had they not been prevented by catches. From these and the swinging lamps I obtained an approximate direction for the shock.

Next morning, having much to do in collecting records from various instruments, I sent a messenger to Yokohama carrying watches to compare the difference in time of the

observation of the shock, and to make general inquiries about the damage.

One observer in Yokohama, Mr. W. H. Talbot, wrote me that the weight of his pendulum which had been put up only a few days previously for the purpose of earthquake observations, had parted company with the wire and had smashed the glass on which the records were to be written. His house had received a cant, and the chimneys had been so much twisted as to be dangerous, neccessitating their immediate removal. Another observer, Mr. J. Bisset, wrote me that he had endeavoured to obtain the time of the shock, but had been interrupted by a falling lamp, clouds of soot, and a quantity of bricks coming down the chimney occasioned by the fall of every thing above the roof. He farther told me that his windows had been broken, the window catches drawn, and that there had been much damage generally. It being evident that much damage had been done, I drew up the following series of qnestions, which were printed on sheets of paper and, through the kindness of Mr. W. H. Talbot, the editor of the *Japan Gazette*, and the interest taken by him in earthquake phenomena, were issued to the subscribers of that paper.

1.—Do you know with accuracy at what time the shaking commenced? This can perhaps be answered by persons who were on board ship and had chronometers at their service.

2.—From the *first* swing of a lamp, the roll of a billiard ball, the direction of fall or projection of a body, the oscillation of a liquid in a vessel, or by any other means, can you tell pretty accurately the direction of the shock?

3.—What was the nature of the damage done to your house?

4.—In what direction did the chimneys fall. If they were rectangular in shape, did they fall broadside or end ways?

5.—Did you observe that any objects had a clear fall, say, for instance, like a tile from the *edge* of a roof, or like a vase from a mantelpiece? If so, what was the *vertical* height through which the body fell; the horizontal distance, measured on the ground, to which the body was projected; and the direction of throw?

6.—Were any objects like columns overturned? If this was the case, in what direction?

7.—Were any objects like chimneys twisted, if so, what was the direction of turn? For instance, was it from E. through N. towards W. or *vice versâ* from E. towards S. and on to W.? A simpler description will perhaps be to say whether, looking down on the object. the twisted portion has followed, or turned against, the hands of a watch?

8.—Were any serious cracks formed in the walls of your house? If there were such cracks formed what was their direction and in

what walls were they formed? In the case of stone or brick buildings, what is the width of the crack? If any of the above questions are answered relating to houses, please give the situation of your house with regard to the points of the compass, and also say whether it stands on the edge of a bluff or cliff, and on which side of the house this bluff or cliff may be.

9.—At the time of the shock was there any one who did *not* feel it? If so where were they? It is believed that many severe shocks may be passed by unnoticed by persons when out walking.

10.—Did the motion produce any effects of sickness, headache, &c.?

11.—Was any rumbling sound heard before or after the shock?

12.—Were any peculiar phenomena observed which have not been referred to above?

Altogether about five hundred copies of these questions were printed, nearly all of which were issued. Those which were returned filled in were as follows:—

From Yokohama	11
„ Tokio	14
„ Yokosuka	1
Total	26

These twenty-six reports have been extremely useful, and all the information they contain is embodied in the following paper. I here beg to tender my sincere thanks to those who sent them.

So far as I have been able, in extracting from these reports I have used almost the identical words of those who wrote them. It will therefore be easy for the writers to recognize their own observations, and if there is any doubt of the accuracy of my quotations or my rendering of their meaning I hope to be corrected.

For several reasons I have in most cases avoided individualizing either my informants or their houses, but should they wish me to do so I shall be most happy to comply with their request.

In most instances the observers, like myself, were in bed at the time of the shock, and therefore, owing to the suddenness with which the confusion of falling tiles, chimneys, and plates, and the creaking timbers of a rocking house burst upon them, observations which needed to be made whilst the shock was going on, were either not made at all, or were not so accurate as those made by persons who hap-

pened to be awake at the time, and had the phenomena presented to them more gradually.

Besides the information received upon the printed forms, several persons seeing from the *Gazette*, the *Weekly Mail*, and the *Herald* in the columns of which papers, through the kindness of the editors, my inquiries had been inserted, answered me by letter. Of communications like these I received four.

As answers to private communications addressed to residents of Tokio, Yokohama, Kobe, Niigata, Sendai, and other places, I received thirty.

To determine the area over which the shock extended, a letter was sent to all the principal towns of the twenty-two nearest provinces to Musashi. As answers to these letters sixty post cards were received.

Altogether then, after issuing five hundred printed forms and over one hundred letters, one hundred and twenty written communications have been received.

Although the number of letters I have received is very large, many of them are but repetitions of each other, whilst others, like the sixty post cards from the country, are but mere records of the fact that on the night of the 21st of February a shaking had been felt. Then the fact that many of the replies I received were to the effect that the writers were unable to give me any information, will explain why, from apparently so many letters, so little has been given in the following pages.

To information of this description I have added my own observations, derived from a number of instruments and contrivances with which I have been experimenting upon earthquakes, and from a series of visits to places in, and in the neighbourhood of Tokio and Yokohama.

I must also add the important information derived from the records of the Yamatô Yashiki Observatory, kindly placed at my disposal by Mr. Arai Ikunosuke; the indications of Dr. Wagener's apparatus given to me by Mr. E. Knipping, and the observations of Mr. W. H. Talbot and Mr. J. Bisset, who for some time previous to the shock had been working in Yokohama in conjunction with myself in Tokio.

The manner in which I have treated all this information has been to divide it up and arrange all observations bearing on the same point under separate headings. The observations under these headings have been supplemented with general remarks and deductions.

The divisions of the subject are as follow :—

1. Time at which the shock occurred as observed in Tokio and Yokohama with deductions therefrom.

2. Relation of the time of occurrence to the time of occurrence of subsequent and preceeding shocks.

3. Direction of the shock as determined at different localities.

4. Rotation of chimneys, tombstones and other heavy bodies. Direction of the shock as deduced from these observations.

5. Extent of the shock.

6. Origin of the shock with a short geological description of the rocks in the vicinity of this origin.

7. Direction of the shock in relation to the direction of preceeding and succeeding shocks.

8. Damage sustained by buildings with an epitome of facts connected with this damage. A discussion of these facts :—

(a) In relation to the construction of the buildings.

(b) In relation to the topography of the place where they are situated.

(c) In relation to the nature of the underlying rocks.

9. Cracks in the ground.

10. Projection of bodies like tiles from the edge of a roof.

11. General nature of the movement. Actual motion of an earth particle, as deduced from diagrams drawn on smoked glass plates at the time of the shock, and the projection and overturning of various bodies. Angle of the emergence, and depth of the origin.

12. Sound which accompanied the movement.

13. State of the atmosphere at the time of the shock.

14. General sensations produced on men and the lower animals.

15. Conclusion.

Although many of the observations are such as have before been remarked in other countries, and the conclusions which are drawn therefrom are in very many instances similar to the results obtained by other writers, I hope that here and there a point may be noticed which may to some extent add at least a little to the advancement of seismic science.

Points like these, however, only form a fractional portion of the whole communication, and the paper, therefore, taken as a whole must be looked upon as one which has been written chiefly on account of its local interest, and for the purpose of enforcing truths, as for instance, those which are connected with the effects of earthquakes upon buildings, with which it is desirous that all those who dwell in earthquake-shaken countries should always be familiar.

1.—Observations relating to the Time at which the Shock occurred.

Amongst the various observations which can be made upon an earthquake, the time at which it occurred is one of the most important. Observations of time made at only *one* locality are for a succession of shocks useful when endeavouring to find out the relation between earthquakes and other phenomena, or in comparing their relative frequency.

Observations of time made at *two* places usually give us a rough indication of the direction in which the shock came. If, in addition to two such observations, we had by other means determined the direction of a shock at the two places, on the assumption of the homogeneity of the rocks between the origin and these points of observation, we might determine the velocity with which the earthquake motion had been propagated. With *three* accurate observations of time independently of any other observation, we might, on the assumption of the homogeneity of the strata, determine the direction of the shock, and also its velocity of propagation between certain points. With observations of time made at *five* stations not only could we tell the velocity with which the shock had travelled between different points, but we might also determine the epicentrum of the shock; and if a *sixth* station were given, its centrum. As, however, the velocity with which an earthquake is transmitted is so very great, according to the observations of Mr. R. Mallet varying from 800 to 1700 feet per second, observations of this description need to be made with accuracy, and judging from my own experience all ordinary methods would be extremely unsatisfactory. The best results would undoubtedly be obtained by connecting together automatic instruments placed at several stations situated at sufficient distances apart by electrical connections. If the stations were at long distances apart independent instruments corrected daily with local time might be sufficient. By observations such as these not only should we be able to gain many facts relating to the origin and the motion of earthquakes, but by the varying rates at which the shock had travelled between the different stations many important inferences might be made about the underlying geological formations.

My reason for referring to well known facts like these is chiefly on account of the excellent situation which Yokohama and Tokio occupy for making such observations. With regard to the observations which have been made upon the shock which we are now considering, I am very sorry to say that but little material has been collected upon which any important conclusions may be founded.

In most cases the time at which a shaking commenced is seldom if ever noted, the importance of such an observation not having as yet been sufficiently recognized. In Yokohama, where the shaking was severe, the suddenness of it, coupled with its violence, would have probably been enough even with practiced observers to have made observation of time a matter of secondary importance. At distances farther from the origin where the movement was comparatively gentle, the time at which it occurred has been recorded in such general terms, that the only value of the observations appears to be the determination of the extent of the country over which the shock extended. In some cases the times which have been given vary from each other more than an hour, and if we relied solely upon time it would be doubtful whether they are records of the same shock with which we have to deal. Coupling these facts with the fact that watches and clocks are everywhere so very different in their times, and that for useful results to be obtained we need the time at any station within a few seconds, what I have to record upon this subject will be of little practical value.

Observations in Yokohama.

On the steamer *Takachiho Maru* the shock was observed at 1 a.m. Other observers give me the following times on the morning of February 22nd :—

12.52.00 A.M.	
12.48.00 ,,	
12.50.00 ,,	This was the time at which the clock on the town hall was stopped.
12.49.15 ,,	This observation was made by a good chronometer. The rate of this chronometer, however, is not given.
12.50.00 ,,	
12.45.00 ,,	
12.35.00 ,,	
12.50.53 ,,	Observations of Mr. Favre-Brandt.
12.50.50 ,,	

The two last observations were furnished to me by Mr. Favre-Brandt. Both of them were given by the stoppage of pendulum clocks, which clocks were used for the regulation of chronometers. The times put down indicate Yokohama meantime at which the stoppage took place. These clocks are placed against walls at right angles to each other. Two other similar clocks on opposite walls were respectively retarded eight seconds and nine seconds. This is the first time that any of his clocks have been stopped by earthquakes since Mr. Favre-Brandt has been in Yokohama, which is probably a period of 18 or 20 years.

Two other observations which I have received were made by Mr. W. H. Talbot and Mr. J. Bisset. For some time previous to this shock, these gentlemen and myself had been making observations in conjunction, my observations being made in Tokio. The method employed was at the time of a shaking to quickly draw out our watches, and glance first at the second hand, then at the minute hand, and finally at the hour. In this way I imagine that the time of the commencement of the shock is obtained more accurately than that given by any ordinary automatic machine, which seldom seems to record until the severer part of the motion commences, which is usually the middle of the shock.

From time to time our watches were compared and always after a shock. Notwithstanding all the care we had been able to take, errors of perhaps 10 or 20 seconds would seem to be unavoidable. These errors chiefly arise from the fact that all ordinary watches seen to have an unequal rate at different times during the day, the graduations of minutes in different portions of the face are different, and finally, the carrying of a watch to Yokohama and back in the train almost invariably causes a loss or gain of 10 or 15 seconds. To reduce this latter error to a minimum, several watches are now interchanged and the total loss or gain experienced by the whole journey is divided by two, and one-half is considered as the loss or gain upon the single journey. I may now add that latterly through the kindness of his Excellency Yamaou Yozo, we are enabled to compare our watches at each end of the journey with a chronometer, which, being in one position, keeps a constant rate.

Mr. Talbot's observation was at 12h. 49'. 38" a.m., and he is of opinion that this was the time as indicated by his watch at which the movement was first perceptible.

Mr. Bisset observed the shock at 12^h 52' 2" but on account of the sudden falling of a lamp, bricks from the chimneys, clouds of soot and the like, he thinks, although the seconds were certainly noted, that there may be an error in the minutes,—being one minute slow.

These would make his observation :—

12^h 53' 2"

From the following data the times taken for the shock to travel along the bluff and between Yokohama and Tokio have been calculated. In Tokio I observed the shock by my watch at 12^h 59' 32".—My watch, Mr. Bisset's watch and Mr. Talbot's watch I respectively call M, B, and T :—

On	Feb.	19th	at	4.30 P.M.	M	was	1' 38"	fast	on	B
,,	,,	,,	,,	4.15 ,,	,,	,,	2' 32"	,,	,,	T
,,	,,	22nd	,,	9.30 A.M.	,,	,,	8' 19"	,,	,,	B
,,	,,	,,	,,	11.15 ,,	,,	,,	11' 40"	,,	,,	T

At the time of the shock, therefore, M must have been 7' 26" ahead of B and 10' 16" ahead of T.

Reducing the observations of B and T to the time which would have been shown by M, we find that

B observed the shock at 1.00.28.5 } in Yokohama.
T ,, ,, ,, 12.59.48 }
whilst M ,, ,, ,, 12.59.32 ...in Tokio.

Therefore the shock travelled from

M to T in 16" } Tokio to Yokohama.
M ,, B ,, 56" 5 }
T ,, B ,, 46" 5...Across the bluff in Yokohama.

From the fact that the distance between Tokio to Yokohama is about 16 miles, whilst the distance between the houses of Messrs. Bisset and Talbot is only about a mile, there is evidently in the above calculations a considerable error. This probably arose from the fact that my watch previously to the shock had been going at a quick and probably irregular rate.

It would, however, seem safe to infer that the shock probably reached Tokio a little before it reached Yokohama.

Observations in Tokio.

My own observation as just given was at 12^h 59' 32".

At Shinagawa the shock was observed at 12.48.0°,

In Tokio the clock at the Kobudaigakko, and also others in the same compound, was stopped at $12^h\ 50'\ 0^s$.

At the German legation Mr. von Eisendecher, who made some careful observations on the shock during its occurrence, tells me that the shaking ceased at $12^h\ 59'\ 0^s$ a.m.

From an observation given me by Mr. Knipping, which observation was made, I believe, by Dr. Wagener's seismometer, the shock occurred in Tokio mean time at 12.52.0°.

On Palmieri's instrument at Yamato Yashiki, the shock was recorded as three movements, the times of which are as follows:—

$$\left.\begin{array}{l} 12^h\ 49'\ 22'' \\ 12^h\ 50'\ 19'' \\ 12^h\ 52'\ 22'' \end{array}\right\}\text{Tokio mean time.}$$

The middle one was the large shock.

Out of the various observations the only ones which can be compared with those made by Mr. Favre Brandt in Yokohama, appear to be those which were made by Mr. Knipping and those recorded by Palmieri's instrument; the former being given in Yokohama mean time and the latter in Tokio mean time.

Of Mr. Favre Brandt's observations I take the earlier as being the one which is most likely to be the nearer to the time of commencement of the heavy shock. By adding on 26 seconds to this observation for the difference in longitude, we may say that the heavy shock took place in Yokohama at, or probably a little before, $12^h\ 51'\ 16''$ (Tokio mean time). From which it would seem that as recorded by Palmieri's instrument the shock must have reached Tokio 57 seconds before reaching Yokohama, but according to Mr. Knipping's observation it must have reached Yokohama 44 seconds before it reached Tokio.

All that we can say definitely is that there was no great difference in time between the arrival of the shock at the two places, the probability, however, being because the former of these observations agree with those made with the comparison of watches that the shock reached the two places at or about the same time, reaching Tokio perhaps a little before it reached Yokohama.

Accepting this conclusion as being probably correct, if we join Tokio and Yokohama and bisect this line by another line at right angles, the epicentrum of the shock will be either upon or else a little to the Tokio side of such a line (see the line A B in map). This is, of course, assuming that the rocks in each direction are tolerably homogeneous.

From these latter observations it will be seen how difficult a matter it is to obtain accurate time observations by ordinary means. In the above observations there are probably slight errors in the times themselves, and very likely errors also arise by different instruments or observers not having noted the same portion of the shock. That such errors are likely to be great will be obvious by the inspection of the observations given by Palmieri's machine.

The times at which the shock was felt at different places in the country are mentioned when speaking of the area over which the shock was felt.

Owing to the shock having occurred during the night, the want of standard clocks or the means of comparing ordinary clocks, and the fact that in no case so far as I am aware, was there any attempt to determine the time at which the shock occurred with any accuracy, the deductions based on these observations must only be regarded as rough approximations to the results we have been endeavouring to obtain.

2.—Relation in Time to preceding Shocks.

If we look over the record of shocks published by the observatory at Yamato Yashiki, some of which are given when speaking of direction, it would appear that the shock of February 22nd occurred in the midst of a very active period. Many shocks at intervals of a few days preceded this shock, and many in a similar manner succeeded it. After a large shock of this sort it would seem that we might expect a quick succession of smaller shocks,—and also in many cases before them. In the accounts of destructive earthquakes of nearly all countries, this phenomenon, which seems to indicate a gradual giving way of the crust of the earth or else repeated endeavours to burst through it, is to be remarked.

The relation which this earthquake has to the large ones which preceded it may be judged of from the following extract taken from a table of the great earthquakes of Japan. This table, which contains 355 records, has been compiled from the works of Dr. Naumann, Mr. Hattori, and a number of Japanese books. The dates which are given have been computed, wherever it was possible, by means of Mr. W. Bramsen's chronological tables.

Years.	*Months.*	*Days.*		*Interval in months for Japan.*	*Interval in months for the Yedo Area.*
1771	7	13	Yedo	13...	13
1782	8	22	Yedo		
——	8	23	Yedo, Odawara &c.	.5...	.5
1782	9	10	Yedo	6...	6
1783	3	4	Yedo		
1783	9	—	Kwanto	6	
1792	3	23	Hizen	102	
——	4	20	——	22	137
1794	2	—	——		
1794	11	25	Yedo	7	
1803	12	28	Sado..........................	119	
1804	7	7	Dewa	7	
——	8	5	——..........................	12	
1805	—	—	Dewa		228
1809	4	5	Shinshiu	48	
1810	2	4	Sado..........................	10	
1812	12	7	Yedo..........................	34	
1819	8	2	Kioto	80	
1822	3	12	Oshiu	31	
1822	3	9	Omi	.1	
1822	7	29	——..........................	12	264
1823	7	19	Kioto		
1828	12	18	Echigo	65	
1830	8	19	Kioto	20	
1831	8	9	Kioto	12	
1834	2	—	——	32	264
1835	2	—	Fujiyama....................	12	
1835	7	21	Rikuzen	5	
1847	5	8	Shinshiu	144	
1848	4	27	Shinano	11	219
1853	3	11	Odawara	59	
1854	12	23	Shikoku	21	
——	7	8	——..........................		
1855	7	27	Ise	7	32
1855	11	11	Yedo..........................	4	
1855	12	12	Yedo..........................	147	
1866	3	14	Harima.......................	72	
1872	3	12	Iwami	95	314
1880	2	22	Yedo..........................		

By glancing at this table which refers to 35 serious shocks during a period of 100 years, it will be seen that the intervals at which great earthquakes have occurred in Japan during this time are as irregular as we could possibly imagine. Sometimes there have been periods of rest between the large earthquakes of only one month; at other times the interval has been more than 100 months. In the *Yedo Area* they seem to have happened at about periods of 1, 5, 11, 19, 22, 18, and 26 years. Dr. Naumann who carefully examined a list of 227 earthquakes which he compiled, speaks of cycles of 490 and 980 years. He also speaks of shorter periods, the smallest of which is 56 years, and the highest 81 years; the mean being about 68 years.

Mr. Hattori, discussing a list of 149 earthquakes nearly all of which are included in Dr. Naumann's list, concludes that "on an average there has been one severe earthquake in the country in every ten years."

"In the older records the intervals appear to be longer than in the more modern records and "if we take the nineteenth century alone we find about one earthquake in every five years."

Mr. F. V. Dickins, writing to the *Times* a few months ago, tells us that the Japanese believe that a severe earthquake occurs about every twenty years.

My own opinion is that we ought not to expect to find earthquakes occurring at equal intervals of time, although if we examine the records which we have at our disposal in a proper manner, we may occasionally find a rule governing the time at which they have taken place.

Hitherto, when discussing the periodicity of earthquakes, a list has been taken of the earthquakes which have occurred in some country or set of countries and then criticized. Thus Dr. Naumann, when searching for periodicity, discusses a list including earthquakes which occurred in North Nippon, and those which occurred one thousand miles south in Kiushiu. Mr. Mallet, in his tables of the earthquakes of Europe, groups them to a great extent according to different countries. Although a grouping together of earthquakes according to certain political boundaries may for some purposes be extremely useful, it does not seem thus far to have given us

any definite law regarding the succession of earthquake phenomena.

The problem to be worked out when data such as these I refer to are placed before us seems to be as follows :—

Given a room filled with sticks each of which is being bent, and caused to crackle under a load which has been applied at different times, it is required from us to determine the periodicity of the crackles or the law of their succession Such a problem seems at the outset to be indeterminable, the crackling of one stick interfering with that of the others. If, however, we confine ourself to one stick, I think we should find that at first the crackles succeeded each other in rapid succession, but as time went on they would occur at longer and longer intervals and a law of succession would be obtained. Similarly, on looking for a law in the succession of earthquakes, we ought, I think, to pick out *one* seismic district, and examine it by itself rather than by taking an indefinite number of districts together, such for instance, as are included in certain political limits.

This is a problem which I have worked out for the district round Kioto, but as the subject is a long one I must reserve it for some future communication. If the problem were worked out in a similar manner for Yedo, I think we should find that this earthquake about which we are writing, belonged to a group, the intervals between which were wider than those which occurred two thousand years ago.

3. Direction of the Shock.

One of the most important observations which can be made upon an earthquake is that which tells us something about its direction. By continually noting the direction of the shocks which visit any place, we see whether the shocks are coming from the same quarter; and in the construction of buildings or laying out the directions of streets, a fact of this description might possibly have considerable influence upon our intentions. If we know the direction in which the shocks reach two or more localities, so long as the directions at these places are different by the intersections of them when produced, we may determine the

epicentrum or the point upon the surface of the ground above the origin, from which the shock has emanated.

For reasons such as these it is my intention to give a full epitome of all the facts which tell us anything about the direction of the shaking which I am now discussing.

In many instances the records which I give may be considered as mere opinions of the observers, founded, so far as I am aware, upon no definite observations. How far these are likely to be correct I leave it for my readers to decide, but I may say that I have often met with persons, who, without any definite observation more than that of the general movement of the ground or house, express most definite opinions about the direction of almost every shock they experience.

Observations in Yokohama.

I.—*Observations without Special Instruments.*

1. 40° W. of N. to 40° E. of S.—This observation was made at a house upon the bund at Yokohama, and was given to me in the form of diagram.

2. 22½° W. of N.—This observer also states that the plaster fell from the S. and E. side of the house.

3.—45° W. of N. to 11¼° S. of E. (?) also E. and W.—Bluff. Two chimneys fell to the E. and the corner stone of another chimney fell to the S.E.

4. Lamp swung in all directions.

5. E. and W.—The top of a Japanese stone lantern was thrown to the east.

6. E. and W.—The bottles in a store room fell E. and W.

7. N. 45° E.—A clock fell to the S.W.

8. N. 45° W.—A lamp hanging on a rod four feet in length was seen swinging to the S.E. Porcelain vases and a bronze statue fell in the same direction.

9.—N. 45° E.—Water was thrown out of a foot pan towards the N.E.,—the stores in the store-room fell in the same direction.

10. N. 45° W., N. and S., and N. 22½° W.—At the time of the shock a lamp was seen to swing from the N.W. to the S.E. This was the first shock. With the second shock its

direction seemed to be changed to N. and S., so that, as a resultant motion it moved N.N.W. and S.S.E.

11. N. 22½° W.—From the manner in which a chimney was broken the shock must have been from N.N.W. to S.S.E.

12. N. 45° W.—The house oscillated from N.W. to S.E., and two vases fell in a north westerly direction.

13. N. 45° E.—From a number of observations made upon my premises and buildings, the direction of the shock would appear to have been from S.W. to N.E. Water was thrown out of a foot pan to the N.E. Iron plates in rack fell over to the N.E.

An iron rack carrying 25 to 30 tons of iron bars, tubes, &c. which were lying N.E. and S.W., was shaken endways to the N.E.

14. N. 45° W.—A grave stone was bulged outwards to the S.E.

15. N. 45° E.—Others, however, fell to the S.W.

16. E. and W.—A chimney seems to have received a shock from the east, whilst a wall was driven out towards the west. At this same house two candlesticks fell with their heads to the west, whilst the candles fell with their wick ends to the east.

17. N. 45° W.—A lamp was seen to swing to the N.W.

18. N. 45° W.—Chimneys appear to have fallen to the S.E.

19. N. 22½° W.—The shock appears to have been from the N.N.W.

II.—*Observations with Instruments.*

The only observations which were made with the aid of instruments in Yokohama, were some which were made by Mr. W. H. Talbot at his residence on the bluff.

The first of these were made with a Cacciatore, which is a circular trough notched round the edges and filled with mercury; it is affixed to a pile driven eight feet into the ground and is wholly detached from the building which contains it. At the time of the shock the mercury was shaken over these notches and caught in watch glasses.

The relative quantities which were thus spilled out in different directions are given in the following table:—

N. 40° E.	15.7	S. 40° W.	19.0
N.	24.0	S.	17.7
E.	22.7	W. 5° S.	31.7
E. 45° S.	32.5	W. 40° N.	38.0

From this it would seem that the direction of the shock was nearer to W. 40° N. than to any of the other points which are given, and it might possibly be a little nearer west than this direction.

The second observation which was made, was by means of a long pendulum. This was a pianoforte wire about 16 feet long carrying at its extremity a weight of about 35 lbs. Fixed to this weight there was a sliding pointer resting upon the surface of a smoked glass plate. Unfortunately, to use Mr. Talbot's words, at the time of the shock the weight and the wire parted company and broke the glass. Joining the fragments together it was seen that before the break had taken place two curved lines had been made upon the glass. By examining these carefully it would seem that the first movement of the glass beneath the pendulum had been 20° S. of E., after which it moved due east, it then drew back in a curve first towards the west, and then upwards 20° N. of W. The curvatures of these lines which are about 3 inches in length are very slight, and they may be said to have an average direction of 10° N. of W.

From an inspection of the first group of observations, amongst which I am inclined to regard the swinging of lamps, which were noted at the time of the shock, as being he most reliable, we see that the most likely direction of the shock was from or towards the north-west. In many cases objects like bottles, clocks, &c. seem to have fallen in a similar direction, whilst in other cases they have fallen in a direction almost at right angles to this. The same remark may be made about the chimneys.

The cause of these anomalies would after a close examination no doubt be found in the fact that in the case of many bodies, if they fell at all, they were compelled, either by their shape or from the position they occupied, to do so in a particular direction. Another explanation would be

that there may have been two or more shocks, the directions of which were transverse to each other. If such were the case and it does not seem to be at all unlikely from the nature of some of the observations, we must regard one of these shocks as being the reflected portion of the other. One observer, whom I know to be accustomed to the making of scientific observations, distinctly states that so far as he could judge from a motion of a swinging lamp which he was watching, the first shock was N.W. to S.E. whilst the second was from N. to S.

That such a state of things should have taken place is easily conceived, but to state where the reflection took place would be a somewhat difficult matter.

Direction in Tokio.

I.—*Observations made without Instruments.*

1. N. and S.—Thirteen bottles fell off a shelf towards the north. (Shiba.)

2. E. ¼ S. to W ¼ N.—This observation appears to be founded in the fact that the door posts in a wall in a line S. ¼ W. by N. ¼ E. were thrown out of plumb, whilst those, in the walls parallel to the front of the house, were not affected. (Shiba.)

3. N. ¼ E.—A shed was thrown down to the N. ¼ E. in a direction at right angles to thewalls to which it had been attached. (Shiba).

4. The walls from the S. and E. side of a chimney were detached. (Tsukidji).

5. N. and S.—An Indian club which was resting against the wall fell to the south.

6. N. 3° E.—Water from a wash-hand basin splashed out 2° or 3° to the west of south.

7. N.E.—Water in a wash-hand basin on the second floor splashed out of the S.W.

Both of the above basins stood in a circular hole of a wash-hand stand. (5, 6 and 7 in Surugadai).

8. N. and S.—At the German legation Mr. von Eisendecher, who was up at the time of the shock, observed his lamp swinging north and south.

9. N.E. and S.W.—This direction is given in answer to question No. 2. (Shinagawa).

II.—*Observations made with Instruments.*

N. 29° W.—This observation was given to me by Mr. Knipping. It was made with an instrument belonging to Dr. Wagener.

OBSERVATIONS MADE AT THE YAMATO YASHIKI OBSERVATORY BY PALMIERI'S INSTRUMENTS.

The only observations which were made for the direction of the shock were the records given by the four bent glass tubes containing mercury. The directions of these tubes and the relative extent to which the mercury was caused to oscillate in them are as follows :—

S.S.E.	to	N.N.W.	78°
S.S.W.	„	N.N.E.	52°
W.S.W.	„	E.N.E.	28°
W.N.W.	„	E.S.E.	28° 20′

From these observations it would seem that the greatest motion had been from N.N.W. to S.S.E. The fact that the next greatest motion to this one occurred in the N.N.E. and S.S.W. tube, which is at right angles to this first direction, would seem to indicate that there had been two shocks almost at right angles to each other, as has already been supposed.

From observations made upon several contrivances and instruments which for some time past I have been experimenting with, the following results were obtained.

I. From a Cacciatore similar to that used by Mr. Talbot in Yokohama, mercury was spilt out of the circular trough in different directions in the following proportions :—

N.	56°	S.	40°
E.	30°	W.	6°
N.W.	40°	S.E.	46°
S.W.	13°	N.E.	17°

The direction which this would indicate would be about N.N.W. and S.S.E.

II. Three small iron columns of different shapes fell about 10° W. of N. Two of them had fallen towards the south and one towards the north.

From these it would seem that the shock was in a direction a little west of north.

III. Standing on the top of the same pillar with the iron columns were a number of strips of glass, something like slides for a microscope, on their long edges and arranged radially round a semi-circle.

These glasses were in pairs and their long edges pointed N. and S., N.N.W. and S.S.E., N.W. and S.E., W.N.W., and E.S.E., W. and E., &c., &c., round to south. Four of these pairs fell.

Those on the E. and W. line and those on the W.S.W and E.N.E. lines fell towards the south, as if by a shock from the north or north-north-west.
Those on the north-west line fell towards the north as if by a shock from the S.W., whilst those on the north fell as if by a shock from the west.

This, I may remark, was a special experiment devised to see whether not only the direction of a shock, but the direction from which it came, could be determined by a simple method. The details of this arrangement I hope to be able to describe at some future time.

The result, however, as given appeared to be that there had been two shocks one from the N. or N.N.W., and another from the W. or S.W.

IV.—From the equality of movement experienced in two sets of brick arches at right angles to each other, which movements were measured by special contrivances to be described hereafter, it would seem that the direc tion of the shock had been about N.N.W. or N.W.

V. From the lines traced upon a smoked glass plate by the *swing* of a pendulum, about 20 feet in length carrying a 20 lbs. bob, the direction of the first part of the motion appears to have been about 38° W. of N. After that the pendulum got up a swing, the point moving backwards and forwards about 40° E. of N. in a series of irregular elliptical forms. The length of these elliptical forms is about two inches and their total breadth half an inch. Traced upon them, there are a number of ripples such as I can only produce upon the smoked glass plate by shaking the table,

whilst the pendulum is swinging. These are evidently ripples produced by the earthquake (see Figs. 12, 13 and 14 in the Appendix). They indicate a motion having an average direction about 33° W. of N. A confusion of lines upon the plate was avoided in consequence of the plate being small. After five swings the pointer passed over the edge of the plate and dropped out, and markings ceased to be made.

About 30 seconds after the shock ceased this pendulum was swinging on a line 20° W. of N.

VI. From a smoked glass plate placed under a pendulum with a pointer similar to the above, the direction given was 10° E. of N. In this case the smoked plate was so arranged that at the time of the shock it could move beneath the pointer. The direction which is given is that which was indicated before the plate commenced to move. On another plate similar markings are also given, but from the manner in which these have been confused with marks made during the arrangement of the pointers at the time the instrument was set, it is a difficult matter to separate those which were made by the shock, from those which were made previously.

During the motions of these plates irregular lines were produced, looking something like lines with rough ripples in them. These ripples I shall refer to when speaking of the amplitude of the shock (see Fig. 11 in the Appendix).

About 30 seconds after the shock this pendulum was swinging violently on a 40° W. of N.

From the various observations here recorded it would seem that in Tokio as in Yokohama, there had been two shocks, one of which was almost at right angles to the other; this is evidenced by Palmieri's instrument, by the Cacciatore and one of the long pendulums, and by the manner in which water was observed to splash out of wash-hand basins.

The former of these shocks seems to have been somewhere near N.N.W. and the latter about N.N.E. or N.E.

Rotation of Heavy Bodies.

Of all the phenomena which were brought before us during the last earthquake, the most interesting, perhaps, was the manner in which many heavy bodies like chimneys,

iron safes, and, above all, the monuments in the cemetery had been twisted or rotated.

Upon the bluff more or less turning was experienced by about half the chimneys. In some cases a chimney appeared as if it had been cut off just above the roof, and then rotated through about 20° or 30° so that the corners of the part which had been moved, rested on the middle of the edges of the portion which remained fixed.

The extent of this movement may be judged of by the fact that in many instances it appears to have so far stopped up the appertures of the chimneys, that it became impossible to light fires.

One gentleman, whom I met, overcame this difficulty by fastening levers to the twisted portion of the chimney, and employing men to turn it back again. In this particular instance the chimney may be said to have been only broken across at one point, and its component parts were so strongly bound together that the upper portion of the chimney could be twisted as a whole. In most cases, however, the cementing material joining the bricks or stones together was so weak that instead of the upper portion of the chimney being turned as a whole it was shattered into several parts, and although these themselves may have twisted more or less, the general phenomena of rotation was to the casual observer less pronounced.

One correspondent writes me that his chimneys were twisted from west to east. Another says the chimneys of two houses were turned through about 20° against the hands of a watch, or from north towards west. Another says his chimneys were twisted 8° in a manner similar to the last mentioned. Another had his chimneys which were oblong in section twisted from N.E. $\frac{1}{2}$ N. against the sun, that is to say in the same direction as the hands of a watch move.

A fifth correspondent speaks of statuettes upon a shelf being turned from the east to the south.

Another gentleman writing in more general terms described the motion of the earthquake as being three-cornered, which observation he remarks appears to be confirmed by the twisting of chimneys and gravestones; many of the latter

being twisted 20° against the hands of a watch. Letters which I received from several others spoke of like phenomena. One gentleman, with whom I conversed, told me how a pack of cards which had been left upon the edge of a sideboard, was found after the earthquake scattered on the floor in an arc like form, as regularly as if they had been dealt out to players. This seemed to him to indicate that there might possibly have been a circular motion in the shock. It, however, seems possible that the cards may perhaps have been piled somewhat askew, under which circumstances a rectilinear shock might equally well explain such a phenomenon.

Besides these observations which seemed to many to indicate a circular motion having taken place, remarks bearing on the same point will be found where I speak of the nature of the movement.

At one house which I visited, I saw a chimney the face of which would originally have been parallel to an E.S.E and W.N.W. line, turned against the hands of a watch until the same face would be about S.E. and N.W. At the same house I was shown a heavy iron safe, standing in a position similar to the chimney, which also had received a movement which was almost exactly similar. At another house I saw a chimney the front of which was originally N and S. turned against the hands of a watch until the same face was paralled to a N.W. and S.E. line.

On one house where there were a number of ridges running in various directions, the tiles from these ridges seemed in every case to have been thrown to the left-hand side of the ridge as you looked up along it. On the same house the chimneys were also twisted.

These examples may, perhaps, be sufficient to show what was the general nature of this movement; other examples are given where the damage done to buildings is spoken of. From what I personally saw I am inclined to think that at nearly every house which suffered at all some kind of an example could have been found indicative rotary motion.

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Rotation of Grave Stones.

The most striking examples of rotation, however, were those which were, and I believe still are, to be seen in many of the grave yards. The best examples are in the foreign cemetery where huge blocks of stone, some of which are 2 or 3 feet square and several feet in height, have been turned through several degrees upon their pedestals. The appearance presented by many of them, as for instance, a granite obelisk mounted upon a high pedestal, in the upper part of the foreign cemetery, and also two or three large triangular pyramids standing near it, is very striking. Some stones have simply twisted on their centres, whilst others in addition to their rotation have been shifted laterally. It would appear as if a dancing motion had been set up amongst the stones.

As these movements were so noticeable and at the same time so definite, I made a number of visits to the European cemetery in Yokohama and to cemeteries in other places for the purpose of examining, as closely as possible the conditions under which they had taken place. The general appearance of the obelisk just referred to is shown in fig. 1. In fig. 2 another stone is shown. The position which these stones occupy in the cemetery will be seen by reference to the plan fig. 3. My attention was chiefly devoted to what I saw in the European cemetery because it was only there that I could with certainty depend upon the movements which had taken place having being produced by the earthquake. In Japanese cemeteries stones are to be found inclined in all directions, whilst near the pathways sometimes every other one has been overturned. This overturning of tomb-stones is especially noticeable in the large and beautiful cemetery of Atago-yama in Tokio, where almost every stone standing near a pathway which could be moved by one or two men has been knocked over. The priests, who have charge of the cemetery, attributed it to mischievous visitors, and made especial reference to the soldiers.

In the European cemetery at Yokohama, however, the conditions are different, and I think we are quite safe in assuming that every stone until the time of the earthquake

occupied the same position as it did at the time when it was first put up. Not only do reasons like these make the European cemetery a better field for observation than a Japanese cemetery, but I might add that in the former the various stones are cut with more regularity and are altogether more definite both in their shape, and in their position, than many of the stones we find in other cemeteries.

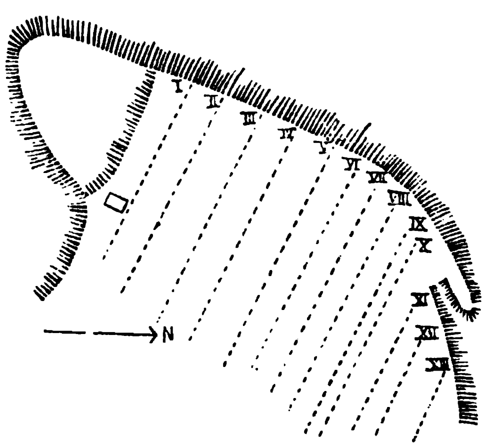
For these reasons when making deductions from these observations I shall lay more stress upon the observations made in the European cemetery in Yokohama than upon those in any other.

I. Observations in the Foreign Cemetery at Yokohama.

The Yokohama cemetery is situated partly on the bottom, partly on the side and partly on the top of a steep bluff about 100 feet in height overlooking the town in a northerly direction.

The portions of the cemetery where movements appeared to have taken place were those which are at the highest elevation, and at the same time are situated near the edge of the bluff. In places such as these, almost every stone had suffered more or less movement, whilst at lower levels and also at places distant from the scarp, although stones exactly similar to the moved ones were to be seen, no movement could be detected.

The first observations which are given in the following tables were made in the French portion of the cemetery, (see fig. 3) which is well marked by a tall granite obelisk and three stones, which in shape are triangular pyramids.



Scale 1 in.=48 ft.

(Fig. 3.)

On the north-west and the south sides it is bounded by steep scarps. The stones which in most cases are a decomposed andesite or else a hardened tuff having a specific gravity of 2.3 are arranged in parallel rows running from 64° W. of N. to 64° E. of S.

Altogether in this portion of the cemetery there are thirteen such rows, the first row being the one parallel and nearest to a small descent in the ground upon the north-west side of the cemetery.

In fig. 3 these rows are shown by dotted lines. In the tables the stones are numbered consecutively in each case com at the north-western end of the row.

The position of each stone relatively to the compass is indicated by one of its sides being so many degrees to the E. of N. The new position of a stone is indicated in a similar manner. The difference in degrees between these two positions gives the amount of rotation. The direction of rotation is indicated by the signs + or —, the former of these meaning rotation in a direction corresponding to the motion of the hands of a watch, or positive rotation, and the latter meaning motion in an opposite direction or negative rotation. The dimensions of the stones are given in inches, the length and breadth of the cross section being given first and the height afterwards.

The other notes made upon the moved stones the records of which are contained in the following table, will probably hardly need any explanation.

I.—YOKOHAMA CEMETERY.

No. of Row.	No. of the stone in the row.	No. of observation.	Rotation. FROM E. of N.	Rotation. TO E. of N.	Amount of Rotation.	Nature of Twist.	Dimensions. Length.	Dimensions. Breadth.	Dimensions. Height.	
I	1	1	115	100	15°	–	14¾	9½	40	Rectangular prism.
	4	2	118	108	10°	–	15½	9½	40	„ „
	6	3	117	115	2°	–	12¾	8½	47	„ „
	8	4	—	—	—	–	—	—	—	Circular column; inclined S. S. W.
	9	5	100	90	10°	–	14¾	9½	41	Rectangular prism.
	10	6	112	90	22°	–	10	16 at bottom 8½ by 8½ at top.		Truncated obelisk.
	11	7	123	109	14°	–	14¾	9½	41	Rectangular prism.
	13	8	114	106	8°	–	14¾	9½	41	„ „
II	1	9	120	94	26°	–	14½	7½ bottom 11½ by 7½ top, height 23½.		Truncated obelisk.
	2	10	112	116	6°	–	14½	8 bottom 11¾ by 8 top.		„ „ „
	3	11	118	110	8°	–	12¾	9½	42	Rectangular prism.
	4	12	—	—	—	–	—	—	—	Circular column inclined S. S. W.
	5	13	118	110	8°	–	13	9½	41½	Rectangular prism.
III	11	14	—	—	—	–	—	—	—	Given way slightly at the base like II. (11).
IV	—	15	—	—	—	–	Two cylindrical columns tending to fall N.W.			
V	3	16	115	104	9°	–	Triangular pyramid. Base 35″ square. Height 59.			
	5	17	—	—	—	–	Circular column inclined S.S.W.			
VII	1	18	—	—	—	–	Triangular pyramid like V. (3).			
	2	19	—	—	—	–	Circular column inclined S.S.W.			
	7	20	116	98	18°	–	7½	12	27	Rectangular prism.
VIII	1	21	—	—	—	–	30	43	52	A rectangular block of stone. A second block resting on the top is twisted similarly
XIII	1	22	125	102	23°	–	16½	19 at base		8¼ sq. at top. Height 6 ft. Granite obelisk.
	5	23	—	—	—	–	8.			Rectangular block; slight twist.

The numbers in the second column give the number of the observation, and refer to the directions of shock deduced from these observations given in Fig. 6. The observations following this table are numbered in a similar manner.

In the lower portion of the cemetery no disturbance was observed to have taken place. In the upper portions of the cemetery which are situated far away from steep slopes, except in the position of one stone it was also remarked that no disturbance had taken place. This stone was a Greek cross with a heavy head about four feet high, its cross section being 5 in. x 10 in. On account of its base being set in another stone it fell to the S. W. (24). In Fig. 4, plans drawn to scale of the first and ninth stone in the first row and of the third stone in the fifth row are shown. The original position is given by dotted lines.

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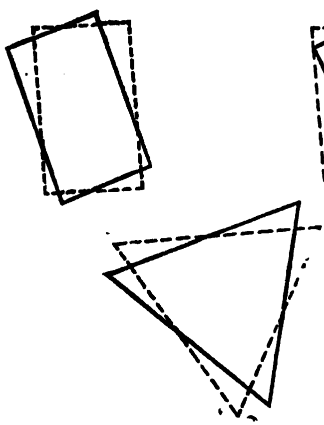


V. 3.

Fig. 4.

II. Southern Extremity of Cemetery.

This portion of the cemétery is like the portion just described, namely, a spur with steep sloping sides projecting out from the main hill.

The only stones which are at all noticeable are three large monuments of which the two following are moved.

		E. of N.			
No. of observation	25	77°	1° or 2°	+ 15×7×51	Rectangular block shifted an inch or two to the N. and W.
„ „ „	26	167° 162°	5°	— 24×24×70	...Rectangular block.

III. Japanese Cemetery (west end of bluff.)

27 & 28.—This cemetery like the others is situated on the edge of a steep slope.

Here fourteen stones appeared to have had a slight negative twist and two a positive twist.

The general direction of the long side of one of these stones, which are all rectangular prisms, is 15° E. of N.

IV. Japanese Cemetery (east end bluff.)

This cemetery is on the left side of the road leading up camp hill. Like the others it is situated on the top of a hill faced with steep scarps.

The stones are rectangular prisms standing on stone bases (29.)

One stone measured 13″ x 13″ and was 4 feet in height; it was twisted negatively through 15°. Its new position being 139° E. of N. turning as if eventually to be East and West.

Altogether in this cemetery fifteen stones which had been moved were observed (30.)

Nine of these had a negative twist and six of them a positive twist.

V. Aizawa Cemetery (west end of bluff.)

This cemetery which is one of the largest near Yokohama, is situate near the head of a gently sloping valley. Going up the valley it lies upon the right-hand side. The graves are nearly all of them situated upon the slope of a hill. This slope is not sufficiently great that we should expect any great disturbance to have taken place.

Altogether amongst many hundreds of stones I only saw eleven stones which had been twisted and the movements were in all cases extremely slight.

Six of these stones had a positive twist and six a negative twist (31.)

VI. Homoku (a small cemetery near the sea.)

Two stones were observed to have twisted positively from 280° to 284° (33).

Another stone was turned in the same direction from 3° to 6° (34).

VII. Homoku (a cemetery on the side of a hill.)

One stone was seen to have turned negatively from 247° to 233°, (35) whilst another had turned about the same amount positively. This latter, however, seemed to have been twisted many years ago. Farther on two stones had a slight negative twist until one of their sides bore 131° E. of N. (36). Another stone, turned positively, bore 145° (37). Most of the stones run in lines 135°, that is, from N.W., to S.E. and they are not twisted.

The priest living here thought that the shock came from N.E. to S.W.

VIII. Negishi.—At a small cemetery on a hill near this place the following observations were made:—

(38)	Stone turned from	360° to 3°	direction	of motion	positive.
(39)	„	„	360° to 350°	„	„	negative.
(40)	„	„	269° to 262°	„	„	„
(41)	„	„	335° to 325°	„	„	„

Number 40 was moved S.S.W. up a sloping base, and number 41 had been moved or shaken back to the W.S.W.

IX. Hope's Inlet.—Near this place on the west side of the valley, a stone was turned positively from 314° to 330° (44). On the east side of the valley there is a cemetery situated on low ground. Here the stones have not suffered any motion.

X. Treaty Point.—Here is a temple at the entrance to which there are two stone dogs. One of these dogs has been twisted positively from 123° to 126° (46), and the other one negatively from 123° to 118°. This latter dog, however, is broken and has probably been put in the twisted position in which we now see it.

Explanation of the Rotation.

From the observations which have now been given, I think it will be admitted that the rotation of bodies was a phenomenon of common occurrence during the time of the earthquake. The question now before us is to determine how this motion was brought about.

In many earthquakes similar phenomena have been observed and explanations have been given. Mallet, in his

account of the Neapolitan earthquakes, makes especial reference to them.

One of the most natural and at the same time most simple explanation is to suppose that during the shock there had been a twisting, or back and forth screw like motion in the ground. Amongst the Italians and the Mexicans earthquakes producing an effect like this are spoken of as "vorticosi." Where I describe the nature of the motion of the earthquake it will be seen that several observers appear to have detected such a motion, and what is more, regard the twistings they subsequently observed to have taken place as confirmatory of their impressions. In the Calabrian earth, quake not only were bodies like obelisks twisted on their bases but straight rows of trees seem to have been left in interrupted zigzags. These latter phenomena have been explained upon the assumption of the interference of direct waves and reflected waves, the consequence of which being- that points in close proximity might be caused to move in opposite directions. Reflections such as these would be most likely to occur near to the junction of strata of different elasticity, and it may be remarked that it is often near such places that much twisting has been observed.

Another way in which it is possible for twisting to have taken place would be by the interference of the normal and the transverse waves which probably always exist in an earthquake shock, or by the meeting of the parts of the normal wave itself, one having travelled in a direct line from the origin whilst the other, travelling through variable material, has had its direction changed.

Mr. Mallet, however, has shown that the rotation may have been in many cases brought about without the supposition of any actual twisting motion of the earth,—a simple backward and forward motion being quite sufficient. If one block of stone rests upon another, and the two are shaken backwards and forwards in a straight line, and if the vertical through the centre of gravity of the upper block does not coincide with the point where there is the greatest friction between the blocks, rotation must take place. If the vertical through the centre of gravity falls on one side of the centre

of friction the rotation would be in one direction, whilst if on the other side the rotation would be in the opposite direction.

In the earthquake with which we have to deal, although the above explanation is simple, and also in many cases probably true, it hardly appears sufficient to account for all the phenomena observed.

If the stones in the Yokohama cemetery had been twisted in consequence of the cause suggested by Mr. Mallet, we should most certainly have found that some stones had turned in one direction whilst others had been twisted in another. On looking at the actual state of things, however, it will be seen that every stone,—the stones being in parallel lines I may remark,—has *revolved in the same direction,* namely in a direction opposite to that of the hands of a watch.

As it would seem highly improbable that the centre of greatest friction in all these stones of different sizes and shapes should have been at the same side of their centres of gravity, an effect like this would be explained by the conjoint action of two successive shocks, the direction of one being transverse to the other.

Although fully recognizing the sufficiency of two transverse shocks to produce the effects which have been observed in Yokohama, I will offer an explanation of this phenomenon which was first suggested to me by my colleague Mr. Gray, which appears to be simpler than any with which I am acquainted.

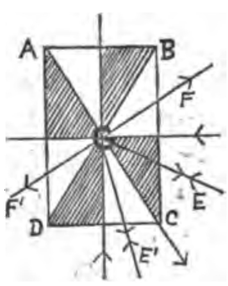


Fig. 5.

If any columnar-like object, for example a prism of which the basal section is represented by A B C D (see fig. 5) receives a shock at right angles to B C, there will be a tendency for the inertia of the body to cause it to overturn on the edge B C. If the shock were at right angles to D C, the tendency would be to overturn on the edge D C. If the shock were in the direction of the diagonal C A, the tendency would be to overturn on the point C. Let us, however, now suppose the impulse to be in some direction like E G, where G is the centre of gravity of the body. For simplicity we may imagine the overturning effect to be an impulse given through G in an opposite direction, that is in the directioe G E. This force will tend to tip or make the body bear heavily on C, and at the same time to whirl round C as an axis, the direction of turn being in the direction of the hands of a watch. If, however, the direction of impulse had been E′ G, then, although the turning would still have been round C, the direction would have been *opposite* to that of the hands of a watch.

To put these statements in another form, imagine G E′ to be resolved into two components, one of them along G C and the other at right angles, G F. Here the component of the direction G C tends to make the body tip on C, whilst the other component along G F, causes revolution.

Similarly G E may be resolved into its two components G C and G F′, the latter being the one tending to cause revolution.

From this we see that if a body has a rectangular section so long as it is acted upon by a shock which is parallel to its sides or to its diagonals, there ought not to be any revolution. If we divide our section A B C D up into eight divisions by lines running through these directions, we shall see that any shock the direction of which passes through any of the octants which are shaded, will cause a *positive* revolution in the body; that is to say, a revolution corresponding in its direction to that of the movements of the hands of a watch: whilst if its direction passes through any of the remaining octants the revolution will be *negative* or opposite to that of the hands of a watch.

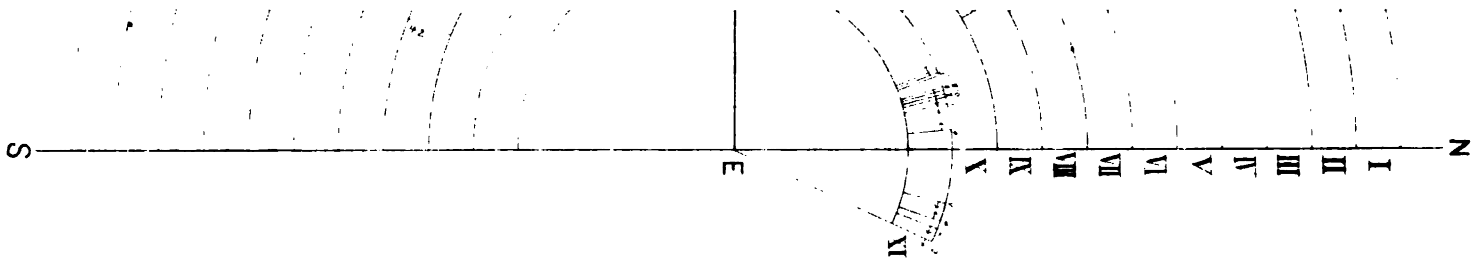


Fig 6. Direction of Shock at Yokohama and Tokio as shown by the Rotation of Stones.

From the direction in which any given stone has turned, we can therefore give two sets of limits between one of which the shock must have come.

Farther it will be observed that the tendency of the turning is to bring a stone, like the one we are discussing, broadside on to the shock; therefore, if a stone with a rectangular cross section has turned sufficiently, the direction of a shock will be parallel to one of its faces, but if it has not turned sufficiently it will be more nearly parallel to its faces in their new position than it was to its faces when in their original position.

If a stone receives a shock nearly parallel with its diagonal, on account of its unstability it may turn either positively or negatively.

Similarly, if a stone receives a shock parallel to one of its faces, the twisting may be either positive or negative; but the probability is that it would only turn slightly; whereas in the former case, where the shock was nearly parallel to a diagonal, the turning would probably be great.

Proceeding in this way I might discuss the various phenomena which groups of twisted stones might present. The effects produced by shocks upon stones of different shapes might also be treated, but as such problems are so numerous, and at the same time the solutions of them are apparently so simple, I will at once proceed to the discussion of the actual phenomena of rotation which have already been observed.

The direction of the shock as deduced by observations made upon the rotation of stones at and about Yokohama have been plotted in Fig. 6. These directions are indicated by short radial lines placed in a series of concentric circles. These circles are ten in number and the lines they contain represent observations made at ten different localities. Each of these circles is marked with a Roman numeral corresponding to the numeral in the record of the observations.

DIRECTION OF SHOCK AS INDICATED BY ROTATION AT YOKOHAMA.

CIRCLE I (Yokohama foreign cemetery). The straight lines indicate the directions of the faces of a number of rectangular stones in their new positions after having been

twisted. The directions in which these stones have turned or were turning in order to assume this position, that is, to become broad side on to the shock, is indicated by a small arrow. From these observations it would seem that the shock may have been nearly E. and W. In all observations like these it may be remarked that the shock might have been exactly at right angles to this direction.

Besides these directions, there are four broken lines A A and B B which are limits of the direction in which a shock must have come to have given the direction of turning which was observed, this direction being in every case a negative one.

Amongst these observations five dotted lines will be seen. These lines indicate the direction in which certain columns have been canted. In all cases this canting was very slight, and Mr. Snow, who accompanied me when making these observations, seemed to think it doubtful whether these movements had been made by the earthquake or not. On the diagram all the observations are accompanied by a small number so that they can each be referred, either to my tables of observations or by help of the plan, to the actual stones themselves.

The last mentioned observations have been placed in this table for convenience in making reference. Strictly speaking they ought to have been included amongst the observations on direction already spoken of.

CIRCLE II. (Southern extremity of the European cemetery).—Here the only two observations which have been made, when taken conjointly, seem to indicate an east and west direction.

CIRCLE III. (Japanese cemetery, west end of the bluff). —From the position of the stones in this cemetery it would seem that the shock must have been 15° E. of N., or 15° S. of E. The latter is the direction which is indicated by 27. As limiting directions which could produce a negative rotation the shock must have been either between 15° E. of N. and about 30° W. of N. or else between 15° S. of E. and about 30° N. of E. The latter is indicated by 28, 28.

CIRCLE IV. (Japanese cemetery east end of the bluff.)—The direction as given by one stone is numbered 29.

Altogether in this cemetery I counted six stones which had been twisted positively and nine which had been twisted negatively.

Assuming that this difference in direction of turning was due to slight difference in position, the shock must here have been either nearly parallel to the sides of such stones, or to the diagonals of their cross section.

As, however, the angles of turning is in all cases very small, seldom, perhaps, exceeding 3 or 4 degrees, it is more probable that the shock was parallel to the former of these directions. As these stones are in parallel lines running $57\frac{1}{2}°$ E. of N., the shock was probably either in a direction $57\frac{1}{2}°$ E. of N. or else $147\frac{1}{2}°$ E. of N. (see 30-30).

CIRCLE V. (Aizawa cemetery).—Reasoning as in the last case it would seem that because the sides of these stones are 283° E. of N., that the shock had been either in a direction 283° E. of N., or else 193° E. of N. (see 31.) Here, however, the gate-keeper pointed out two large stones standing on pedestals which had been moved $\frac{8}{10}$ in. to the S.E. (see 32.)

CIRCLE VI. (Homoku cemetery, near the sea).

CIRCLE VII. (Homoku cemetery, on a hill).

CIRCLE VIII. (Negishi cemetery, on a hill).

CIRCLE IX. (Hope's Inlet).

CIRCLE X. (Treaty Point).

The directions which have been plotted for these last five localities will be understood by reference to the observations made at the localities themselves, and from what has been said about the previous observations.

Of all these observations those which can be most relied upon are those made in the European cemetery. In the other cemeteries it is quite possible that deductions may have been made from observations upon stones which have been twisted by causes other than the earthquake. Nevertheless, even admitting that such may be the case, the probabilities are that the observations made upon stones which were twisted by the earthquake will greatly exceed all the others, and therefore the general result ought to point towards the truth.

From *inspection* of the diagram Fig. 6 it would seem then, that the directions of the shock at the ten localities under discussion were about as follows :

At	No.	I.	about.........	E. and W.
"	"	II.	"	" " "
"	"	III.	"	" " "
"	"	IV.	"	S.W. or N.W.
"	"	V.	"	N.N.W. or N.W.
"	"	VI.	"	N.N.W.
"	"	VII.	"	N.W. or W.
"	"	VIII.	"	N.N.W. or W.S.W.
"	"	IX.	"	N.N.W.
"	"	X.	"	N.W.

Speaking still more generally, by an inspec- tion of these results we might say that the shock at and about Yokohama was, as inferred from the rotary movements of grave stones, about E. and W. or E.S.E. to W.N.W.

In making this statement we purposely make it broad because at every different locality we should expect to find a difference in direction of the shock.

By a careful analysis of the different directions which have been observed for different places it would have been easy to have given a definite statement as to the direction. As this resultant direction, however, would have varied with the number of observations recorded, rather than attempting to show a result which would have an appearance of being absolutely accurate, I have preferred to indicate the impossibility of obtaining such a result by the adoption of the above method.

In concluding this part of the subject I may remark that several other cemeteries besides those mentioned were visited, but as the phenomena of rotation were not observed in any of them they have been omitted. *Farther I may add that it was only in those cemeteries situated on or near to the edge of bluffs that a twisting movement was at all marked.* Although movements were so pronounced and definite in the upper parts of the Yokohama foreign cemetery, in the lower portion, although stones similar to those at higher levels were examined, the fact that motion had taken place could not be detected.

XI. Tokio.

In Tokio the only examples of rotation. which I have met with were those in the grave yard upon the top of Atago-yama. Here there is a very large cemetery containing many stones which, both from their appearance and the dates upon them, are very old. Many of these stones have been over turned by mischievous visitors. A number of them, however, were slightly twisted, and as the marks of twisting were fresh and it is not the habit of mischievous persons to try and turn heavy stones standing upon pedestals, I accepted these as being the work of the earthquake. Farther I may remark that these twisted stones are only situated on the edges of steep scarps and in positions similar to those of the stones which were twisted in the Yokohama cemetery; this I take as farther evidence that the examples of rotation, which I have noted, were really the work of the earthquake.

The hill on which this cemetery is situated is in reality a long ridge, on both sides of which there are steep scarps 90 to 100 feet in height. The strike of the ridge is from about N. to S. Nearly every stone which has been twisted is situated on the edge or else very near to the edge of one of the scarps.

I omit my observations on a few of the very large stones, which from the absence of any marks shewing their old position and also from their size I cannot imagine to have been twisted during the last shock. These measurements are given in degrees East of North.

1.	205 to 212	twist positive.	Not considered in calculation.
2.	188 to 195	,,	
3.	200 to 190	negative.	
4.	208 to 200	,,	Lateral shift to the North.
5.	195 to 190	negative	
6.	200 to 195	positive.	
7.	203 to 198	,,	
8.	185 to 195	,,	
9.	95 to 105	,,	
10.	185 to 195	,,	
11.	182 to 190	,,	
12.	192 to 202	,,	
13.	190 to 205	,,	
14.	185 to 175	negative.	

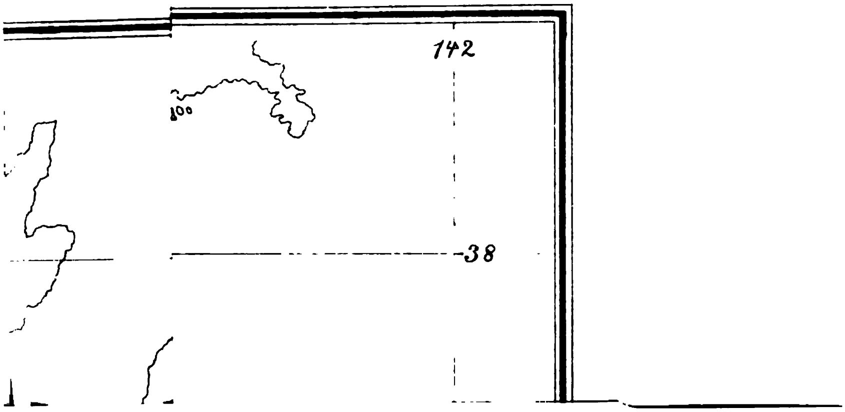
All the stones which have been spoken of are rectangular parallelopipeds, the average dimensions of which will be a little less than those which were measured at Yokohama.

In Fig. 6.—Circle XI., the directions which these revolutions give are indicated in the same manner as those of the similar observations made in Yokohama.

As a general result it would seem that the shock was either about N.N.W. or N.

V. Extent of the Shock.

Hitherto nearly all that has been said about the shock has been based on information derived in or near to Tokio and Yokohama. At these two places the effects were probably as severe as they were at any other places, and on account of their containing many European buildings they were certainly the best marked. In the country although the motion seems to have been strong enough to throw water out of half filled buckets and to cause lamps to swing through an arc of two feet, owing to the flexibility of the houses little or no permanent damage was experienced. In consequence of this and from the fact that the earthquake occurred in the middle of the night, although numerous enquiries have been made, it was very seldom that any thing beyond the record that a severe shaking had taken place could be obtained. From observations which have been made upon this last earthquake, I feel that even if it had been as strong as that which devastated the Neapolitan districts in 1857, from the nature of the Japanese constructions it would have been a difficult matter to obtain information which would be given under similar circumstances by the shattered aspect of a European building. The best information which can be obtained appears to be that which is offered by the effects produced amongst the stones of grave yards. As, however, the monuments in the greater number of grave yards are already in a state of ruin, chiefly owing to the work of mischievous visitors, in sorting out the stones which have been overturned or twisted by the earthquake it would be necessary to exercise considerable judgment. Also, as the nature of the measurements which have to be made need both



the origin.

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care and time this information could not be obtained with any degree of certainty by means of a letter; and in Japan it would be a necessity that the place should be visited by a person to some extent accustomed to the making of scientific observations.

In some cases the reports which have been received from different localities, for help in obtaining which my best thanks are due to my assitant Mr. Toshiwo Nakano, may perhaps be founded on the experiences of a single individual. If this has been the case we must remember that what has been reported as a slight shock might by another observer have been spoken of as being very severe. Similarly at places distant from the origin one writer might report a slight shock whilst another might say that no shock was felt.

That this has actually been the case will be seen by a reference to those places from which I have been fortunate enough to obtain several records.

Thus for instance one record from Maibashi says that the shock was not felt at all, whilst another says it was felt slightly. Again, one record from Uyeda simply states that there had been a shock; another says it was a slight shock, whilst a third speaks of it as having been severe.

The relative intensity of the shock at different places has been indicated upon the map which accompanies this paper, but from what has just been said it will be seen that it will not be advisable to place too much reliance upon such indications.

The times which are given for the occurrence of the shock are, as might naturally be expected, considerably at variance. Some of them, as for instance those in Ise, are so far away from the time as recorded in Tokio that I am inclined to think that it was not the shock which we are considering which these observers wrote about, but a shock that happened to occur about the same time.—This view is strengthened when we see that they seem to indicate a shock which was stronger or as strong as that which was felt at places situated much nearer to and between them and the origin.

The records which indicate to us the area over which the shock was felt are as follows.

They were chiefly collected by writing letters to the different ken, by letters sent to private friends, by communications received from persons who happened to be travelling in the country at the time, and from a few notes which I gathered together during a journey I made shortly after the shock along the Tokaido the translations of the letters are as literally as possible.

IWASHIRO.

1. *Dategori.*—After close enquiry it is not clear whether there was a shock or not.

2. *Iwasegori, Sukagawa.*—It was very strong in this district; such shocks are rare in modern times. The old people say that "because this district is very mountainous, "strong earthquakes do not occur, and even in the year of "Ansei, none of the buildings were broken. We think that "this shock corresponds to that of Ansei."

3. *Aidzugori, Wakamatsu.*—No one remembers the intensity of the said shock.

4. *Nishi Shirakawagori.*—In this district, it shook very slightly a little before 1 a.m. on the day referred to. Some people knew about it; others did not know. We think it was not particularly strong.

5. *Wutagori & Namekatagori, Nakamura.*—In this district, it shook very slightly. It was so weak that the people, who slept soundly, did not feel it.

6. *Kikutagori, Iwamayagori, & Iwakigori.*—There was a shaking about 1 a.m. on the 22nd Feb. It was not very strong.

YECHIGO.

7. *Iwafunegori, Murakami.*—Not felt.

8. *Niigata.*—1. In this district, the shock was very slight. We can not speak definitely about it. 2. Not felt. 3. Not felt at all.

9. *Koshigori, Nagaoka.*—In this district, it shook very slightly about 12 p.m. on the night, of the 21st of February (22nd?). Only a few people knew about it. We have no machine; therefore can not give any details.

10. *Naka-Wuwonumagori, Tokamachi.*—In this district, the shock was very slight. Many people did not know about it.

11. *Naka Kubikigori.*—After close enquiry no one can tell us anything about it. If felt, it must have been feeble.

Kotsuke.

12. *Adsumagori, Nakajo.*—In our district, at about the same hour and during the same night you have mentioned an earthquake occurred. It continued for about 25 or 26 seconds. It was, at first, weak, but at the end, strong. There have been but few shocks in modern times. All places in this district felt the same.

13. *Maibashi.*—1. Felt but slightly. The volcano Asama has not rumbled more than usual. The people here all said that the newspaper report about the threatened outbreak of Asama was unfounded. 2. Not felt.

14. *Tonegori, Takasaki.*—1. In our district, it was weak. It felt like the shaking of the house during a storm. The intensity of the earthquake cannot be ascertained without instruments. 2. Severe shock at 1 a.m.

Shimotsuke.

15. *Nasugori, Odawara.*—1. Not certain. 2. The earthquake was about midnight. As it is now some time ago we can not tell much about it.

16. *Shiwoyagori, Yaita.*—1. Slight shocks. 2. We have not yet a seismometer at this office. Therefore we can not ascertain the intensity of the shock. We felt it very slightly at about the time you mentioned.

17. *Utsunomiya.*—Severe shock about 1 a.m.

18. *Tsukagori* and *Samukawagori, Tochigi.*—In our district it was not so strong. As it was in the night, there were some who did not know about it. We think it shook for 20 or 30 seconds.

Hitachi.

19. *Tagagori, Tukahagi.*—In this district, it shook very little, but we can not tell you the exact time.

20. *Nakagori, Sugaya.*—In this district it shook pretty severely, but we have no means by which to ascertain the strength or the time of the shaking.

21. *Makabegori, Kita Somagori.*—1. In this district, it shook so slightly, that those who slept soundly did not feel it. 2. As in this district we are without instruments, we can not say anything about the nature of the shock, but a slight earthquake occurred at about the time mentioned. 3. Severe shocks.

22. *Kashimagori, Hokoda.*—It shook all over the district, but its strength can not be ascertained. It is thought that it was not remarkably severe.

Shimosa.

23. *Wunakamigori, Chosi.*—For about one minute between 8 and 9 minutes past 1 a.m., it shook, but it was not particularly strong. A loud sound was heard.

24. *Narita* (sheep farm).—Felt severely.

25. *Hamugori, Inbagori,* and *Somagori.*—As we are without earthquake machines, we can not ascertain the strength of shocks, but they are very rare. The people were surprised and ran out of doors. No person or animal was wounded, and no house was broken. It was severe.

Kadzusa.

26. *Yamabegori* and *Musagori.*—In this place it was strong, but not so violent as to shake down either the buildings or the trees. As it occurred during the night and we are without instruments, the strength and the direction &c. are not known.

27. *Isumigori, Katsura* and *Ohara.*—The fishermen did not observe any disturbance in the water.

28. *Bodagori, Kisaradsu-mura* and *Adsumamura.*—In this district, it shook three times at about 1 a.m. on the 22nd day, of the 2nd month. The strength of the shaking is not known. Neither houses nor furniture were destroyed nor were they turned over. The sailors and fishermen did not know about it.

AWA.

29. *Asahinagori, Wada.*
30. *Asahinagori, Ohkawa.* There were no fishermen out
31. *He-gori, Katsuyama.* at the time when the shock
took place so we are unable to get any information.

32. *Nagasagori, Mayebara.*—There were no fishermen out, so that we can not obtain any information.

33. *Taira-gori, Asahina-gori, Nagasa-gori.*—Very severe shocks were felt but we do not think that they were so severe as the one felt at 7 a.m. on the 3rd of December. A bucket which was nearly full of water splashed out about three tenths of its contents.

34. *Taira-gori, Kachiyama-mura.*—It shook pretty severely for rather a long time. It was, however, thought to be somewhat weaker than the shock felt about 7 a.m. at the beginning of the 12th month of last year. On that night, there were no fishermen on the sea, and therefore nothing is known about the effects which might have been felt there.

35. *Nagasagori, Mayebara-machi.*—It shook for about one minute; the strength of it was for modern times quite exceptional. There was no injury done to the houses. As at that time there were no fisherman on the sea, nothing is known about effects which might have been felt there.

MUSASHI.

36. *Chichibu-gori, Omiya.* — In this district it shook severely at about 50 minutes past 12 on the night referred to, but we can not ascertain its strength, &c. Earthquakes have been very rare in modern times.

37. *Hachioji.*—Felt severely.

38. *Kuraki-gori, Kanagawa.*—Not felt (?)

39. *Kuraki-gori, Kanagawa.* — In this district, houses were not seriously damaged. Some of the walls were a little broken. The fishermn do not remember feeling it.

SAGAMI.

40. *Yokosuka.*—Two time pieces stopped at $12^h\ 0'\ 57''$ p.m., on the 22nd February. A watch shewed $1^h\ 2'\ 0''$ p.m.

The shock appeared to be from E.S.E. to W.N.W. No damage to the house. The shaking was severe.

41. *Uraga.*—The fishing boats did not feel any disturbance.

42. *Mameko.*—The fishing boats were not affected.

43. *Yose.*—This place is on the Koshiukaido about 15 ri from Tokio. The shock felt like a series of short rapid jerks followed by a jump or two.

44. *Atsugi*—This is a large town between Tokio and Oyama. A large stone lantern was overturned and the ruins now lie at the N.E. corner of the pedestal.

45. *Odawara.*—Sharp shock.

46. *Hakone.*—Felt severely. On one of the mountains between Hakone and Atami a stone looking like a mill stone, 12 inches square in section has been turned against the hands of a watch and moved 2 inches towards the east.

47. *Kita Surugori, Ohara.*—In this office, instruments have not yet been prepared, and we can not give exact particulars about the shock. Earthquakes have been rare in modern times, since the great earthquake in the period Ansei (1854-1858). The shock you speak of was severe.

48. *Miuragori, Uragamachi.*—In this district, it shook for about one minute, and those who were asleep were awakened. It was not so strong that we ran out of doors. Neither was water thrown out of flower-vases, nor were bottles thrown down from shelves. No part of the house, or other buildings were destroyed. Neither the sailors nor the ships in the port, nor the fishermen out in their boats knew about it.

SHINANO.

49. *Kita Saku-gori, Iwamurata.*—In this district, it began to shake from the east, at 30 minutes past 12 on the night mentioned, and it continued for 2 minutes. As we are without instruments the strength of it can not be ascertained. However it was not strong enough to destroy or alter either the mountians, rivers or even the houses. As the observations in Minami Sakugori were just the same as our's they do not send any report.

50. *Uyeda.*—1. Shock felt at 11^h 0′ 40″ p.m. the day before yesterday; it lasted 2 seconds. (A telegram without date.) 2. The shock was severe. It happened at 12^h 50′ 0″ a.m., 3. In this district, it shook slightly at about 1 a.m. on the 25th day (22nd ?) of the 2nd month, and it continued for about 45 or 46 seconds. Many of us did not know about it, but we were told this by those who live in Uyeda.

51. *Kami Minochi-gori, Nagano.*—On the day mentioned we had neither rain nor wind, and it was very clear weather. Suddenly at about 10 minutes to 1 it began to shake very slightly, the motion being from the north-east. There was a noise like far distant thunder. Many persons did not wake. The furniture in the house did not creak or rattle. The shaking continued for about 1 minute.

52. *Shimo Ina-gori.*—In this district, it shook between 30 and 40 minutes past 1 a.m. As compared with the length of the time, it was not so violent. Strong and long shakings have been very rare in modern times. Nothing was destroyed.

53. *Suwa-gori, Kami-Suwa.*—In this district, it shook about 1 a.m. on the night mentioned. It was stronger than earthquakes usually are. Some people ran out of doors, but it was fortunate that nothing was destroyed.

54. *Higashi Tsukuma-gori.*—In this district, it shook greatly at about 50 minutes past 12 p.m. It continued for about 10 minutes. At one time we thought of running out of doors. It was very fortunate that nothing was destroyed.

KAI.

55. *Kita Komagori, Nirasaki.*—In this district, instruments have not as yet been prepared, and therefore we can not ascertain particulars about shocks. Those who slept soundly were awakened by the one you mention. A hanging lamp was swung about one shaku, (1 ft.) right and left.

56. *Kofu.*—The most severe shock since 1876. It appeared to come from the south. Some of the people ran out of their houses.

IDZU.

57. *Kimisawagori* and *Tagatagori.*—In this district, it shook about the time mentioned but there were some who

did not wake. Others however ran out of doors. As we have not an instrument, we can not tell you the strength of it.

58. *Kamogori* and *Nakagori*, *Shimoda*.—In this district, there was only a sound. It was then just 3 o'clock. The strength, &c. of the shock is not known, for we live in a remote district and have no machine to measure shocks.

SURUGA.

59. *Numadsu*.—Shock felt.

60. *Fujigori*, *Yoshiwara*.—In this district, there are no earthquake machines and therefore we do not know exactly what may have been the strength of the shock. At the time of the shock, a scholar was studying in a quiet room, where a lamp was hanging down on a wire four shaku (4 ft.) long; suddenly it began to shake, and it continued for about 10 minutes. The lamp was shaken each way 2 sun and five bus ($2\frac{1}{2}$ in.), first to the right and then to the left.

61. *Wudogori* and *Abegori*, *Shidsuoka*.—Felt slightly.

62. *Shitagori*, *Fujiyeda*.—In this district it shook a little on the day mentioned, but it was not so strong as in Tokio.

TOTOMI.

63. *Sanogori* and *Jotogori*, *Kakegawa*.—At about 2 a.m., on the 22nd, a weak earthquake was felt from the north. It continued for 12 or 13 seconds. Some persons did not know about it. A roaring sound was heard.

64. *Shikichi-gori*, *Hamamatsu*.—1. In our district we are without seismometers. Therefore we can not exactly tell the strength or the direction of the shaking, but that there was an earthquake I know by the shaking of the house. 2. A severe shock was felt about 11 p.m. The hotel people thought that the house was falling.

MIKAWA.

65. *Atsumi-gori*, *Toyohashi*.—In this district, it shook very slightly at about 10 minutes past 1 a.m., and afterwards nothing happened. As we are without seismometers we can

not give any definite information about it, but we think it must have been weak.

66. *Hatsu-gori, Mishiwo.*—In this district, it shook very slightly at about the time mentioned; as it was in the night, many did not know about it. We think it was not very severe.

ISE.

67. *Toshi-gori* and *Iga-gori.*—In this district, it did not shake at the same time as in Tokio, but a very slight earthquake occurred at about 5 a.m. on the 23rd.

68. *Iitaka-gori* and *Iimo-gori.* — In this district, the shaking was so slight that many people did not know about it.

69. *Watarai-gori, Yamada.*—In this district, it shook very slightly about 3 a.m. on the day mentioned, but most people did not know about it.

70. *Isshi-gori.*—In this district, it shook about the time mentioned but most people slept very soundly and did not know about it. Although a few knew, they did not run out of doors.

71. *Miye-gori, Yokkaichi.* — In this district it shook slightly about the time mentioned.

OWARI.

72. *Kaito-gori* and *Kaisei-gori.*—In this district slight shocks were felt.

73. *Higashi Kasugai-gori.*—We can not tell you anything about the shaking because it was so very slight in this district.

74. *Nagoya.*—A slight commotion was felt during the night. Out of about 100 people examined only one or two felt it. They all guessed at the time—some said it was at at 11 p.m., others 11.30 p.m., others 1 a.m. and others again at 2 a.m

Two men who were awake gave the following particulars:—

One said it was felt at 11.30 p.m. and lasted 10 seconds. It was just sufficient to make the rings in some drawers rattle. It was a horizontal, oscillatory sort of motion.

The other living at Koromo, 15 ri from Nagoya, said he felt it at 2 a.m. and that it lasted 5 or 6 seconds. The direction was N.N.E. and S.S.E. Altogether the motion was slight, and it gradually increased and then decreased.

MINO.

75. *Atsumigori, Kakumugori* and *Katagata-gori, Gifu.*—In our office, we are without seismometers, and therefore we can not tell either the extent or the strength of the motion on the day you mention.

76. *Ohnogori, Masudagori & Yoshikigori.*—In my district, at about 1 a.m., on the 22nd of the 2nd month, it shook for 1 second very slightly. After 2 or 3 seconds it shook again for about 3 seconds more. It appeared to come from the north-east, and every one was awakened. At this time a Fahrenheit thermometer showed about 23°, and a barometer stood at 29.33 inches.

77. *Ohnogori* and *Ikedagori.*—A few of the people who live in the two kens, Ohno and Ikeda, that is, 8 ri east and west, and 14 ri north and south from here, knew about it. We can not ascertain the strength, the direction or the extent of the motion.

78. *Gujo-gori, Yawata,*—Slight shock.

79. *Yena-gori, Ohi-mura,*—In my district, the shaking was so slight that nine tenths of the people did not know about it.

OMI.

80. *Kaga-gori, Minakuchi.*—In this district, a sound like that of a cannon was suddenly heard at about 6 a.m., on the 22nd of February. It continued for about 10 minutes, and was rather strong.

81. *Inukami-gori office.*—In this district, it did not shake.

82. *Ika-gori* and *Nishiasai-gori.* — In this district, it shook very slightly at the time mentioned.

HIDA.

83. *Ohno, Takayama.*—A little after 1 a.m. shocks came from the N.E. lasting about 3 seconds.

KAGA.

84. *Ishikawagori, Kanazawa.*—In this district, it did not shake at the time mentioned. At about 10 a.m., on the 9th of March, it shook very slightly. Many of the people did not know about it.

YETCHIU.

85. *Kaminikawa, Toyama.*—In this district no one seems to have felt it.

PLACES OUTSIDE THE LIMITS OF THE MAP.

86. *Sendai.*—Nothing felt.

87. S. S. "*Wakanoura Maru,*" twenty miles south of Shiriyasaki, did not feel it.

88. S.S. "*Genkai Maru,*" between Nagasaki and Shimonoseki, did not feel it.

89. *Kioto.* Nothing felt.

90. *Kobe.* " "

91. *Nagasaki.* " "

The greater number of places which have been here mentioned are indicated upon the accompanying map. On the same map the chief mountain ranges are also given. In looking at these latter it must be remembered that in nearly all cases accompanying the indicated range there are many flanking ranges and projecting spurs. The range which surrounds the origin of the shock that is to say, the mountains bounding the provinces of Sagami, Musashi, and the southern part of Kotsuke and Shimotsuke, must have formed a powerful barrier against the spreading of the shock into the countries which lie beyond. In most places the height of this barrier will be from 3,000 to 5,000 feet but in places it rises to form peaks which are more than 8,000 feet in height. The breadth of the barrier is variable but it will probably be broadest in northern Kodzuke.

On the map the severity with which the shock was felt at different places has been indicated by the following numbers :—

1 means a slight shock.
2 " " moderate "
3 " " severe "
? " that it is doubtful whether the shock was felt or not.
0 " that the shock was not felt.

Speaking generally the area indicated on the map is that over which the shock was sensible.

The area over which it was felt somewhat severely is bounded by the line dated Feb. 22nd 1880. This contour, it will be remarked, is very irregular, spreading out like two wings of unequal lengths, one running N.W. into Shinano and the other running N.N.E. up to Shimodzuke and Iwaki. That the earthquake should have been felt severely for a greater distance in this latter northerly direction might have been anticipated from the contour of the country.

In the north-west direction a shock would meet with formidable barriers in the form of high hills placed at right angles to its path, whilst in the northerly direction the hills in the first place are comparatively low and in the second place they are situate end on to the direction of propagation, so that a shock could advance up the broad flat valleys which lie between them. What is here said is based on the supposition that the shock originated near to Tokio or Yokohama as seems to be indicated by the manner in which the shock was felt at different points.

Comparing the indicated area with the areas over which other earthquakes have been felt in Japan, we see that it is by no means the smallest. On my map I have indicated the extent of country over which the earthquakes of 1847 and 1855 were felt. These I have taken from the map given by Dr. E. Naumann in his valuable paper "*Ueber Erdbeben und Vulcanausbrueche in Japan.*" (See Mittheilungen der Deutschen Gesellschaft für Natur-und Völkerkunde Ostasiens, 15tes Heft). From what I have read of the 1855 shock, accounts I have heard of it from persons who were living at Tokio and Yokohama at the time it occurred, from grave-stones which have been pointed out to me as having been overturned by it, and buildings which were broken, there is no doubt that it was much more severe than the one about which I am now writing.

Under these circumstances we must regard the boundary lines of the 1847and 1855 shocks as meizoseismals including an area within which the shock was most destructive.

Intensity of the Shock.

Assuming that in any sufficiently large districts over which shocks have been felt, the rocks with regard to their density, elasticity and the like have an approximately equal value, it would seem that some estimate of the relative intensity of shocks in such districts might be obtained by a measurement of the areas which were shaken.

Mallet when speaking of great earthquakes divides them into the three following classes according to the areas which was shaken :—

1st	class	earthquakes	have an extreme radius of 540	geographical	miles.
2nd	„	„	180	„	„
3rd	„	„	60	„	„

The Nepaul earthquake of 1833 had a radius of about 250 miles.

The Cutch earthquake of 1819 had a radius of about 180 miles.

The Lisbon earthquake of 1755 had a radius of about 600 miles.

The Chili earthquake of 1822 was felt 600 miles north and south from its origin.

The earthquake of which we write had certainly a radius over which it was *sensible* of 120 miles.

Assuming that these shocks which have extended over such vast areas have had their origin at about the same depth from the surface, if we consider the quantity of material moved to be proportional to the moving force, then because the quantities of material moved will be as the square of the radius of the disturbed area, the intensity of the shock will vary as the square of this radius. Regarded in this way the intensities of the above shocks will be:

The Lisbon and Chili shocks	600^2
Nepaul	300^2
Cutch	180^2
Tokio	120^2

If we call the Lisbon and Chili shocks 100

Then the others will be :

Nepaul	25
Cutch	9
Tokio	4

A shock which has only a sensible radius of 60 miles, which is probably the case with many of the small shocks we so often experience, would, according to this scale, have a value equal to unity.

Although I think that I have under rather than over-estimated the areas over which the greater shocks which I have given extended, whilst I have by no means under-estimated the shock which created so much alarm in Tokio and Yokohama, it will be seen that our experiences were those of a shock, the actual intensity of which was probably only the one hundredth part of the intensity of some which have been experienced in other portions of the globe.

As there are so many conditions which it is impossible for us to take into account when comparing the relative intensities of different earthquakes, the comparison I have just given must only be regarded as an assistance in the formation of conceptions on this subject, and certainly not as a calculation which is intended to give any thing approximating to a true measure.

By looking over the records of the great earthquakes which have been felt at various times in Japan, it would seem that in bye gone times catastrophes as great as those we read of in countries like South America and India have happened here. Whether they will ever be repeated is problematical; on the whole, it is probable that the seismic energy of many areas has been growing less and less, but as Sir William Thomson said, we must remember that it is quite possible that the last bubble in the porridge pot may be equal to if not greater than the first.

VI. Origin of the Shock.

Having now discussed all the evidence which I have been able to gather together relating to the time at which the earthquake occurred, its direction, and the area affected, I will now proceed to the determination of the locality from which it originated.

From the time observations which we have at our command it would seem that because the shock reached Yokohama at almost the same time as it reached Tokio, the origin

of the shock must be at about an equal distance from these two places. This is, of course, assuming that the rocks lying between these two places and the origin are similar in their character, which, if this origin is not very remote, from what we know of the geological nature of the surrounding country, is not at all unlikely to be the case. If the shock reached Tokio, say 30 or 40 seconds before it arrived at Yokohama, we may imagine that the origin of the shock was six or eight miles nearer to the former of these two places. Therefore, if we join Tokio and Yokohama by a straight line and then bisect this by a line at right angles to it, the epicentrum or point upon the surface of the ground above the origin of the shock, will be somewhere either upon or slightly to the Tokio side of such a line. Such a line which has been before referred to is marked A A.

Let us now turn to the observations which we have respecting direction. By drawing lines through the different places paralled to the most probable directions it would seem that our epicentrum ought to be determined with some approach to accuracy.

The observations which appear to me to be the most trustworthy I take to be as follows :

1.—*In Yokohama.*—Observations (numbers 10, 12, 25,) on swinging lamps made at the time of the shock. N.W. and S.E.

2.—"Cacciatore" observation. Made by Mr. W. H. Talbot, W. 40° N.

3.—Pendulum observation made by Mr. W. H. Talbot, 10° N. of W.

4.—Observations on grave-stones indicate a direction which was E. and West or E.S.E. to W.N.W.

5.—*In Tokio.*—Observation (number 43) on a swinging lamp, N. and S.

6.—Observation by Mr. Knipping N. 29° W.

7.—Observation by Palmieri's instrument N.N.W.

8.—Observation with a "Cacciatore" N.N.W.

9.—Observation on falling columns 10° W. of N.

10.—Pendulum observation 38° W. of N.

11.—Observation on grave-stones N.N.W. or N. and S.

It will be observed that although particular observations are selected in the above list these observations include the bulk of the others,—the directions noted by them being often intermediate to those here given.

Farther it must be observed that several of the directions lying outside those here mentioned may be identified with the reflected shock, the existence of which appears to have been tolerably certain.

These directions are drawn upon the map and are numbered to correspond with the above list.

From an inspection of this map it seems that the 10 selected observations give us by their intersections no less than 25 points from which we may suppose the shock to have originated.

Although it is probable that the shock was produced by a jar-like action extending over a certain area rather than from a mere point, it is difficult to conceive of its having originated over so large area as would be included between all those points. It therefore remains for us to select out of these points those which appear most in accordance with our other evidence.

If, for instance, we consider that some of the selected observations like Nos. 7, 8 and 11 coincide with each other, we ought to give to them a greater value than the others. If we do this we see that our origin ought to be situated either in the bay or at a short distance from it on the land, in an easterly direction from Yokohama, in fact, near the place where the greater number of intersecting points are to be found.

From our time observations we see that the origin ought to be near the line A B. Putting these facts together I should be inclined to think that the origin, in all probability lies within the small ellipse which is described in this portion of the map.

That the origin does not lie altogether on the opposite side of the line joining Tokio and Yokohama may be inferred from the fact that the directions given at these two places do not intersect in that direction. This statement, however, excepts one or two observations of doubtful value.

Assuming for the moment that deductions based upon these doubtful observations are true, then the shock in spreading from this centre ought to have produced approximately as great an effect when spreading towards the N. W. as it did when spreading towards the S.E. that is towards Yokohama and Tokio. The records which we have received from the country are, however, contrary to such a supposition.

The area which I have marked as being probably that from which the shock originated, is about 9 miles long and $4\frac{1}{2}$ miles broad. This area is parallel in its length to the general strike of the faults in this district.

It is quite possible that the shock may have originated by the formation of a fissure, and the shakings which were felt at Tokio and Yokohama originated along the surface of a broken plain rather than from a single point.

Geological Character of the Districts near the Origin.

The locality which I have indicated as being near the origin of the shock, lies on the eastern shore of Yedo Bay, at no great distance from Kisaradzu, a village on the west coast of the province of Kadzusa.

The following few notes which I made upon the geology of this district in December 1877, may perhaps be of some value when considering why shocks might be expected to emanate from such a quarter. Commencing at the head of Yedo Bay we have a very flat coast which, owing to great depositions of mud which are being continually brought down by several large rivers which enter this portion of the bay, together with an elevatory action which seems to be very active, is rapidly pushing its way seawards. Evidence of the rapidity with which elevation has been going on are given to us at Yokohama and near Yokosuka where we have *pholas* borings, existing in a soft rock which is easily weathered away, several feet above high water mark. The nature of the soil and the beds of shells it contains at and near Yedo indicate the same thing, as also does history and old maps (*vide* a paper on the Bay of Yedo by Dr. Edmund Naumann in *Petermann's Mittheilungen* 25 Band, 1879, page 123; also *Notes on the Pre-historic Remains of Japan* &c,.

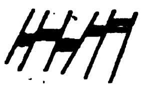
by J. Milne. *Transactions of the Asiatic Society of Japan* Vol. VIII Part I).

At Kisaradzu there is a flat sandy shore but some distance inland a few low hills can be seen. Standing in the water a short distance out from the shore there is a *Tori* or stone gateway forming the last of a series which stand on the land, leading up to a temple. Whether this was originally built in the water I am unable to say. If it were built on the land it would seem to indicate that the last movement had been one of subsidence. I believe there are other similarly placed *Tori* between this place and Tokio.

About one and a half miles from Kisaradzu at the village of Sakai you come to some cliff-like slopes covered with briars and shrubs. These slopes are made up of beds of sandy materials capping beds of grey tuff, a section of which would correspond with a section at Kanagawa or Yokohama. Continuing towards the south you quickly enter upon a hilly country which is in every respect similar to that upon the opposite side of the bay near Yokohama or Yokosuka. On all sides there are low steep hills covered with scrubby wood. Winding in and out between these hills, there are narrow valleys filled with muddy rice fields. This character of scenery seems in Japan to be every where indicative of soft tuff rocks, and it is often possible, without seeing a rock, to predict their nature from the general aspect of the country. At one or two places fossil shells were found in this tuff. Just beyond Saunki these rocks commence to be folded, and on the top of a hill just outside this town the road passes through a cutting in a gentle anticlinal. It is not at all improbable that some of the valleys about which I have just spoken may have been first marked out by these foldings, which gave an initial direction for the flow of water and other denuding agencies. Since then, by a continuous action, water has been flowing and denudation going on, the general result of which has been to cut out the valleys as we see them at the present day.

Some distance beyond this point instead of beds of tuff we meet with beds of volcanic breccia dipping at an angle of 15 degrees towards Yokohama. Here we get many bays

with rough rocks jutting out like sentinels to guard their entrance. The general dip of these rocks seemed to be across the bay, but in places we met with anticlinal and synclinal foldings in the cliffs, beneath which we travelled as we journeyed along the shore. At some places the dip was as much as 45 degrees. Just beyond Kaniya then is a formidable looking cliff-like range of hills which forms the boundary between Kadzusa and Awa. Here the beds of breccia are almost turned on end. From a little town beyond the cliff-like range, which is called Nokogiriyama, there seemed to be a steep anticlinal, the strike of which was across the bay. In many places faults were observable; in some places these were so numerous that the cliffs appeared to be quite serrated.



(Fig. 7.)

Fig. 7.—Represents such a set of faults between Kachiyama and Honjo.—Beyond this, tuffs and breccias continue to be met with to the extremity of Awa.

From the manner in which the rocks are crumpled, metamorphosed, faulted and bent up to form high hills at the boundary between Kadzusa and Awa, it is evident that we have here the maximum development of a great disturbance which has done much to give a character to the mountain scenery on the west side of Yedo Bay. Whether this crumpling action is still going on it is a difficult matter to say, but it is an easy thing for any one who has visited this district to imagine that rocks bent so far out of their original position must be in a state of strain, and that from time to time they give way. That fractures should be thus formed is almost indisputable, especially when we consider the number of fractures which have taken place already. Breakages of this sort may possibly produce earthquakes, and it is perhaps catastrophes of this sort which sometimes alarm the inhabitants of the Alps.

On the opposite side of the bay we find analogous conditions. Commencing at the north near to Yokohama we have beds of unaltered tuff. Travelling southwards we find this tuff bent into gentle anticlinals; here and there we meet with faults. In Yokosuka harbour these faults are especially well marked. A little further on we come to the beds of breccia.

One side of the bay is from a geological point of view to a very great extent the counterpart of the other.

How the fractures were produced it is difficult to say. Perhaps the forces which produced the contortions are still increasing and sections of the strata are being bent still further. Perhaps the forces are decreasing and the strata are no longer able to support themselves in the position to which they had originally been forced.

The cause of the bending is probably due to a flow of heat producing expansions or contractions. And that there is great heat at no very great depth beneath this area is suggested to us by the volcanic nature of the surrounding districts.

If the shocks were produced in the way which is here suggested, namely, by the giving way of contorted and strained strata, volcanic agency can only be regarded as the antecedents of the immediate cause. However, if we refer to the map it will be seen that it is quite possible volcanic agency may have been the immediate cause itself. Lying off the mouth of Yedo bay and stretching for hundreds of miles down into the Pacific we have a line of volcanic islands commencing with Ooshima in the north and reaching to the Bonins and the Ladrones in the south. From time to time many of these are in eruption. In 1877 Ooshima was in violent eruption, and it would even seem that some of these islands may have been formed during the historical period. If we continue the line from Kosushima through Niishima, Toshima and Oshima, we see that it passes up Yedo Bay through the district which we have indicated as being the probable origin of the February shock. From the soundings given on the English admiralty charts it seems that near to these islands on the western side we have water about 80

fathoms in depth. The neighbouring sea is, however, very deep and in places the bottom has not been met with at a depth of 500 fathoms. From the north-west end of O-shima running to the southern extremity of Sagami the water varies in depth from 50 to 80 fathoms. If, however, we leave this line and pass either to the east into the Uraga channel or to the west into Odawara Bay, we immediately meet with water 300 or more fathoms in depth although the distance from the main land is not much more than two miles.

Here we have something like a submarine bank which is the prolongation of a line of volcanos.

The conditions then are that we have a line of volcanos 1,500 or more miles in length. The northern end of this line is continually active and if we project this portion of the volcanic fissure 60 miles further it will reach Yedo Bay. That this line has continued itself northwards even during historic times is indubitable, and we are not making suppositions beyond conception if we supposethat this line is still endeavouring to open for itself vents still further north. If we take the alternative and imagine a volcanic line which had forced for itself vents for a length of 1,500 miles suddenly terminated at its most active end we should, I think, be more unreasonable.

It may therefore be, that beneath Yedo Bay there is a point under which volcanic agencies are endeavouring to force a way, and it is these repeated efforts which reach us in the often registered S.E. earthquakes.

The nature of the bottom of this portion of the bay is I believe as yet but little known. The deepest soundings as given on the chart are about 16 or 17 fathoms. Not far from Kisaradzu in the bay at Kuranami, Mr. Arai Ikunosuke tells me, there are two fresh water springs bubbling up, from which the junks can take fresh water. At Yokohama it is said that a similar phenomenon may be observed. Some years ago when making excavations near the railway station at Yokohama a hot water spring is said to have been tapped but this eventually died out.

Whether there are any traces of volcanic energy beneath the surface of Yedo bay might perhaps be ascertained by a series of temperature observations. The question is an interesting one, and especially to those who imagine that there is a possibility of a Fujiyama or an Ooshima being built in Yedo bay as Aphroessa was in the Gulf of Santorin or Graham's island in the Mediterranean.

Niishima appears to have been the last island which was built. What shall we call the next one?

VII. Direction in Relation to Preceding and Succeeding Shocks.

It would seen to be a natural supposition that if the ground were being ruptured or volcanic forces were acting at one point in an unusually violent manner, this action would commence gradually and that after a violent rupture had taken place there would be a gradual settling down of the broken strata or spasmodic dying away of the forces which produced the main catastrophe. In other words we might in many cases have as a prelude to a great earthquake originating from a particular point, a number of small shocks coming from the same origin, and similarly, after a great shock,a number of small shocks might come to us from a similar point indicating a dying-out of volcanic force or a settling down of strata.

That earthquake shocks come in groups such as these so far as their direction is concerned, may I think be seen by glancing over the records of an observatory like that at Yamato Yashiki in Tokio.

How this supposition is borne out in the case of the earthquake of February 22nd will be seen by reference to the following list extracted from the records of Yamato Yashiki.

Date		Time H.	M.	S.		Intensity	Direction
Jan.	6th	11	15	0	a	0° 50′	S.S.E.
„	6th	4	37	0	p	2.40	S.S.E.
„	13th	11	30	0	a	—	—
„	17th	7	10	0	p	—	—
„	18th	10	0	0	p	—	—
„	20th	9	7	0	p	—	—
„	23rd	10	0	0	p	—	—
„	25th	0	20	15	p	—	—

Date	Time H. M. S.		Intensity	Direction
Feb. 1st	11 0 0	p	2.30	S.S.E.
„ 4th	1 32 0	p	1.0	E.S.E.
„ 12th	8 57 11	p	1.0	E.S.E.
„ 12th	10 39 0	p	0.30	S.S.E.
„ 22nd	0 49 22	a	—	—
„ 22nd	0 50 19	a	78°	S.S.E.
„ 22nd	0 52 15	a	—	—
„ 25th	6 46 14	p	0° 25′	S.S.E.
„ 28th	0 28 0	a	—	—
Mar. 2nd	1 18 0	p	—	—
„ 2nd	10 14 55	p	—	—
„ 3rd	6 32 0	p	0° 30′	S.S.E.
„ 5th	4 35 0	a	—	—

(The severe shock of December 3rd, according to the record at the Yamato Yashiki observatory, was S.S.W. and N.N.E.)

Here we have a series of 21 earthquakes, 9 of which travelled in a direction very nearly E. S. E. and N. N. W. The remaining 12 shocks were too feeble to have their direction recorded, but it seems probable that they came in the same direction as those of grater violence.

Before and after these dates we get S.S.W. and W.S.W. shocks, that is to say shocks from a direction approximately at right angles to the directions about which we speak.

The fact that shocks appear to run in series, and that we nearly always have a number of small shocks preceding a large shock coming in the same direction, would seem to strengthen the suggestion that earthquake's like those recorded at Tokio occur in directional groups. This phenomenon, however, is to some extent hidden by the groups of shocks overlapping each other, that is to say by one group commencing before the other has ceased. It is also hidden by the fact that many of the small shocks are too small to be appreciable to the instruments we have at our disposal. From observations which I have been making in conjunction with Mr. J. Bisset and Mr. W. H. Talbot of Yokohama, it would seem that many shocks are felt in this latter place which fail to reach as far as Tokio. Very shortly by the help of instruments now established in Yokohama we hope to

determine to which directional group such shocks belong. From a few imperfect observations already made it would seem that they were the N.W., S.E. group already under discussion. If this is the case, the firm establishment of the supposition I have put forward could be well made by observations made in Yokohama, or what would be still better, by observations upon the opposite side of the bay nearer to the origin of the last great shock.

An observatory established at either of these places would probably register many more tremblings than are felt in Tokio.

By using suitable instruments we might even detect earth tremors and by watching these and noting the manner in which they preceded a shock it seems possible that many earthquakes might be foretold.

VIII. Damage to Buildings, &c

As we see but little prospect of ever being able to prevent the occurrence of earthquakes, our next best study will be to endeavour to obviate, so far as we are able, some of their disastrous effects. The general character of the effects produced upon buildings is well known to nearly every resident in Yokohama. By studying these effects and observing the points which in consequence of their weakness gave way, much may be done to prevent their giving way in future.

When speaking of the phenomena of rotation and projection which were observed, many examples of the damage which took place were cited.

Observations in Yokohama.

The general character of the damage sustained by many of the houses situated on the Bluff at Yokohama, may be gathered from the following extracts taken from various letters I have received.

1. At one house the principal beams were smashed. This was occasioned by the force of the shock and not by the chimneys falling across them. Two chimneys fell to the east &c. Brick walls were cracked the width of the cracks being

about $\frac{1}{4}$ of an inch. The house is situated near the edge of the Bluff and a valley.

2. Plaster fell from the south and east side of the house. Vases, glass ware, &c. also fell.

3. Chimneys were smashed, walls cracked. Looking glass, crockery, &c. were all broken. Debris was everywhere.

4. Chimney was damaged. On the N.W. side of the house there is a bluff.

5. Chimneys slightly twisted.

6. At one house the plaster was cracked, and at another every tile on the roof was shaken up but none fell off. Of the various walls which are cracked the North and South ones are those which have suffered most. The cracks appear to be inclined to the horizon at about 45°. The East side of these houses are untouched. The houses which are here referred to are built on stone foundations, with wooden frames, tile and plaster. The chimneys are of brick and are built on the outer walls. These have suffered less damage than those which are built on the inside or near to the centre of the house. Both these houses are very strong. The lighter built houses seem to have suffered least.

7. A little plaster fell off the eastern end of the house, which faces N.E. It is near the edge of a cliff. The foundations of this house were dug down until clay was reached. Perhaps this lessened the vibration for the house notwithstanding its position escaped with but little damage.

8. The plaster is cracked and some of it fell off upon the N.W. side. The sides of the house face N.S.E. and W.

9. Chimney shorn off. At the eaves of the roof the chimney was strapped to the house by an iron band and it is close above this latter where it has been cut off. The top part of the chimney still stands upon the lower part, but it is twisted. (This house is in the settlement).

10. Brick house situated on a pretty steep slope facing the North. On the east side there is a gulley, and on the south side a hill. On the 3rd of December the whole of the upper part of the wall on the eastern side was thrown down. This was rebuilt at the time of the February shock. Some

vases fell, doors were opened, pictures oscillated, but no serious damage was done.

11. Cracks in some buildings I saw seemed to be perpendicular.

12. Chimneys broken and twisted. On a wall running N.E. by N. to S.W. by S. all the pictures were askew, the N.E. end of the pictures being raised. On the walls at right angles the pictures were not altered.

13. Clocks stopped.

14. The wall paper was torn all along.

15. Chimneys so damaged that fires could not be lighted.

16. Nearly all the chimneys have fallen to the S. E.

17. Chimneys fell, tiles taken off the ridges of the roof &c. Ten windows in a verandah running N. 80 E. to S. 80 W. all broken.

German Hospital.—This is a new brick building built I believe expressly to withstand the effects of earthquakes. Its position is somewhat below the level of many of the neighbouring houses but yet it is so situated that the ground slopes rapidly away from it on several sides. The upper portions of four or five chimneys fell, and twisting was observed. Here and there mortar was loosened and a few joints slightly opened.

So far as I could see, the general nature of the effects which had been produced were similar to those in the other buildings, but they differed from them in not being so serious. In the dispensary many bottles were thrown down.

The Convent, which is a large brick building, appeared to have had every tile shaken off it.

Another house in the neighbourhood was unroofed in a similar manner.

This latter I observed had a very steep pitch.

The damage in the settlement appeared to be very similar in its nature to that which took place upon the Bluff. Chimneys were overturned, shattered or rotated, windows were broken and tiles and plaster were loosened and thrown down. This was on the outside of the houses. Inside th houses, vases, glasses, &c. were overturned clocks wer

stopped, and pictures hanging on walls were caused to swing with violence.

OBSERVATIONS IN TOKIO.

In Tokio the effects which were produced were by no means so severe as those which were produced in Yokohama.

Near my garden gate the tiles and upper portion of the walls of a "godown" were thrown down. From my own house which is chiefly built of wood, one or two tiles fell from the roof.

At the house of a friend, the door posts were thrown out of plumb and a shed over a "godown" was thrown down. The house stands on low ground.

From others the following records were received. At a house in Tsukiji the plaster fell of the north and west sides and two or three cracks were made in the west and inner walls. There were three horizontal cracks one in the west side of the Genka, (porch) one on the outer wall, and one in the inner wall of the passage. There was one perpendicular crack. This was formed in the east side of a passage running north and south. The house which has a frontage 20 degrees W. of S. is a framework of wood filled with kabe, (plaster) with tiles outside.

At another house in Tsukiji the roof was injured at the junction of the chimneys, the partition walls having separated from them on the south and eastern sides. The walls joining on the northern side shew but slight traces of separation. The house is situated on the eastern side of a canal, the road intervening.

At a third house also in Tsukiji there was no damage beyond the displacement of a few small articles.

At many places small objects like clocks, crystal balls and the like were thrown down and water was splashed out of basins. Although we have evidence of violent motion having taken place it does not appear that any serious damage took place.

At the Naimusho, (Home Department) 1 chimney fell.

At the Kaiseikioku, 1 chimney fell.

At the Okurasho, (Finance Department) 1 chimney fell.

At the Daigakko (University) 2 chimneys fell.

These four observations are upon buildings which I believe are built of wood, whilst the chimneys which run through them are of brick.

At Nihonbashi, Awamonocho, a portion of the wall of a "godown" came down burying a man. He was however extricated from the ruins without having sustained any serious injury.

At Asakusa Kuramai, a chimney and some tiles fell.

In fact all through the town, here and there a little damage had been done similar to the examples which have been quoted.

Extent of Motion in Buildings.

From the slow long swing of pictures like Kakemono three to six feet in length, which oscillated backwards and forwards on the wall, it is very probable that the extent through which the upper portion of houses moved was very considerable. In some instances these pictures seem to have swung as much as two feet, and from the manner in which they swung they evidently synchronised with the natural swing of the house. From this it would seem that such a house must have rocked from side to side one foot out of its normal perpendicular position. That the motion was great is testified by nearly all who tried to stand at the time of the shock, it having been impossible to walk steadily across the floor of a room in an upper story. The houses which I refer to are either those which are purely Japanese or else those which are framed of wood and built on European models, a class of building which is very common in Tokio and Yokohama. What the extent of oscillation was in a brick or stone building I have no means of forming any estimate.

In a pamphlet published at the Imperial College of Engineering by Messrs. Perry and Ayrton on "Structures in an Earthquake Country," calculations have been made to determine the period of a complete natural vibration of different structures. For a square house whose outer and inner sections were respectfully 30 and 26 feet and whose height

was 30 feet, the period as calculated by these authors would be about .06 seconds.

At the time of the earthquake many houses seem to have moved like inverted pendulums. On the morning after the shock my neighbour who was living upstairs in a tall wooden house with a tile roof, told me that he endeavoured to count the vibrations and was of the impression that to make a complete swing it took about 2 seconds.

Assuming now that the distance through which the top of a wooden house moved was about 1 foot and the number of vibrations which it made per second were about .5, then the greatest velocity of a point on the top of such a house must have been about 6 feet per second.

General Nature of the Damage.

From what has been said it will be seen that the greatest damage occurred upon the Bluff near to Yokohama. Generally speaking the nature of the damage was in all cases about the same,—chimneys were thrown down, shattered, or twisted, tiles were thrown off roofs, walls were cracked and plaster shaken off their sides, grave stones were rotated. On the inside of buildings, vases and other small objects, were thrown down, clocks were stopped, paper was torn, windows were broken, and everything which was loose was more or less moved.

In Yokohama the damage chiefly occurred in those parts of the town which are situated near to the foot of the bluff, parallel to the creek which runs along its base. Back from this line well out upon the flat ground upon which the greater portion of Yokohama is built, the damage was by no means so serious. It was very noticeable that the Japanese houses, with the exception of a few "godowns" (warehouses) which lost a little plaster, seemed hardly to have sustained any damage.

Amongst the foreign houses on the bluff there appeared to be one or two lying in hollows which also escaped.

Two chimney stacks on the bluff in Yokohama left standing after a fire, in what was apparently a very shaky condition, did not seem to have been in any way affected.

The same was observed about several chimney stacks in Tokio which had been left standing after the great fire.

Discussion of the Principal causes on which the Destruction appears to have been Dependent.

Having now seen what the general nature of the damage has been, it remains for us, partly for instruction's sake, and partly with a desire to put ourselves in a position to avoid like calamities in future, to examine carefully the phenomena which have been placed before us, and sift out from them the various lessons they may present.

If we turn to the buildings in Yokohama I think we may safely say that the destruction was chiefly dependent upon one, two, or all of the following three causes :—

a. The construction of the buildings themselves.

b. Topography of the district.

c. The nature of the underlying rocks.

Although much of what I have to say whilst discussing these three causes is well known to those who have studied earthquakes, I feel that because the lessons which speculations on these points may teach us are so important, it will be hardly necessary for me to apologize for repeating that which is already told.

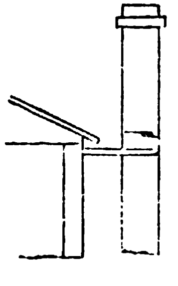
a.—The Construction of Buildings.

In speaking of the effects which have been caused by bad construction I only intend to refer to one general principle, which principle I will call that of "relative vibrational periods." In many instances, chimneys were shaken down, because there was not sufficient adherence between their several parts. Questions like these, which involve considerations respecting bonds, lime, mortar and the like, are so intimately connected with the business of the builder, and at the same time so obvious to us all, that I will leave the remedy for such defects in the hands of those whose speciality is to deal with technicalities of this description. My reason in speaking specially about the principle of relative vibrational periods, which principle was, so far as I am aware, first

ennunciated by Messrs. Perry and Ayrton in a pamphlet already referred to, is, because that principle has been so forcibly illustrated to us in almost every building which suffered serious damage.

If a building were constructed of a material like steel, we can imagine that it might be set rocking to and fro, which if it were shaken by an earthquake it might do in a manner something similar to that of an inverted pendulum, without any danger of its being broken. It would simply rock back and forth with a definite period of its own. In ordinary houses, however, instead of having a single vibration of the whole building to consider, we have to investigate the vibration of a number of parts, the periods of which are all more or less different. These parts, although they are tied together in various maners owing to differences in elasticity, height, thickness, and load they carry, do not tend to synchronize in their swings. Whilst one portion of the building is endeavouring to move towards the right, another is pulling towards the left, and, in consequence, either the bonds which join them or else they themselves are strained or broken. This seems to have been strikingly illustrated by many of the chimneys in the houses on the bluff, which were shorn off just above the roof. The chimneys, which were shafts of brick, probably had a slower period of vibration than the roof through which they passed, this latter vibrating with the main portion of the house which was framed of wood.

A particularly instructive example of this kind which has already been referred to is roughly sketched in Fig. 8.

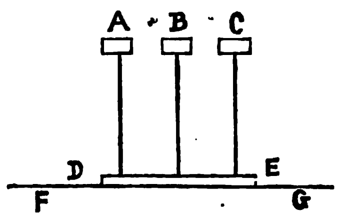


(Fig. 8.)

This is a chimney standing alone, which for sake of support, was strapped by an iron band to an adjoining building. It would seem that at the time of the shock the building moving one way and the chimney another, the swing of the heavy building gave the chimney a short jerk and cut it off. The upper portion being then loose upon the lower part, rotated under the influence of the oscillations in manner similar to that in which the gravestones rotated.

Not only have we to consider the relative vibrations of the various parts of a building amongst themselves, but we have to consider the relation of the natural vibrations of any one of them or the vibration of the building as a whole, with regard to the earth. From the regularity of the curves which are drawn by persons when indicating earthquake motion, it would seem that they anticipated finding that the earth oscillated back and forth at a definite rate. If the vibrations of an earthquake were the result of a single blow, which it is quite possible they may often be, then such a supposition might be justifiable. If, however, a shock is the result of a number of blows of various intensities struck at irregular intervals it is hardly likely that we should obtain periodic vibrations. That there was an irregularity in the impulses of this last earthquake, seems likely, both from our sensations and from the portion of a curve drawn by the motion of the earth which I have given farther on.

Some of the more important results dependent upon the principle of "relative vibrational periods" may be understood from the following experiments:—



(Fig. 9.)

In Fig. 9 A B and C are three flat springs made out of strips of bamboo, and loaded at the top with pieces

of lead. At the bottom they are stuck into a piece of board DE, and the whole rests on a table FG. The legs of this table being slightly loose, by placing the fingers on the top of it, a quick short back and forth movement can be produced. The weights on A and B are the same, but they are larger than the weight on C. Consequently the periods of A and B are the same, but different to the period of C. The dimensions of these springs are as follows: Height 18 inches; A and B each carry weights equal to 320 grammes and they make one vibration per second; C has a weight of 199 grammes and makes 0.75 vibrations per second.

1st Experiment.—It will be found that by giving the table a gentle back and forth movement, the extent of which movement may be so small that it will be difficult to detect it with the eye, either A and B may be made to oscillate violently whilst C remains still; or *vice versa* C may be caused to oscillate whilst A and B remain still. In the one case the period of shaking will have been synchronous with the natural period of A and B, whilst in the latter it will have been synchronous with that of C. This would seem to show us that if the natural period of vibration of a house, or of parts of it, at any time agree with the period of the shock, they may be readily thrown into a state of oscillation which will be dangerous for their safety.

2nd Experiment.—Bind A and B together with a strip of paper pasted between them. The paper which I used was 3/8 inch broad and would carry a weight of nearly 3 lbs. If the table be now shaken as before, A and B will always have similar movements, and tend to remain at the same distance apart, and as a consequence the strip of paper will not be broken. From this experiment it would seem that so long as the different portions of a building have almost the same periods of vibration, there will be little or no strain upon the tie-rods or whatever contrivance may be used in connecting the different parts.

3rd Experiment.—Join A and C, or B and C with a strip of paper in a manner similar to the last experiment. If the table be now shaken with a period approximating

either to that of A and B, or with that of C, the paper will be suddenly snapped.

This indicates that if we have different portions of a building of such heights and thicknesses that their natural periods of vibration are different, the strain upon the portions which connect such parts is enormous, and it would seem as a consequence that either the vibrators themselves, or else their connections, must, of a necessity, give way. This was very forcibly illustrated to us in the last earthquake by the knocking over of the chimneys. The particular case of the chimneys is, however, better illustrated by the next experiment.

4th Experiment.—Take a little block of wood three-quarters of an inch square and about one inch high, and place it on the top of A, B or C. It will be found that, although the spring on which it stands is caused to swing back and forth through a distance of three inches, the little block will retain its position.

This little block we may regard as the upper part of a chimney standing on a vibrating stack, and we see, that so long as this upper portion is light, it has no tendency to fall.

5th Experiment.—Repeat the fourth experiment having first placed a small leaden cap on the top of the block representing the chimney. The cap I used only weighed a few grammes. When vibration commences it will be found that the block quickly falls. This would seem to indicate that chimneys with heavy tops are more likely to fall than light ones.

6th Experiment.—Bind A and B together with a strip of paper and stand the little block upon the top of either. It will be found that the block will stand as in the 4th experiment.

7th Experiment.—Bind A and C, or B and C together, and place the block upon the top of either of them. When vibration commences, although the paper may not be broken, the little block will quickly fall.

8th Experiment.—Take two pencils or pieces of glass tube and place them under the board DE. If the table FG be now shaken in the direction DE, it will be found that the springs will not vibrate.

In a similar manner if a house or portion of a house were carried on balls or rollers, as has already been suggested, it would seem that the house might be saved from much vibration.

9th Experiment.—Set any of the springs in violent vibration by gently shaking DE instead of the table, and then suddenly cease the actuating motion. It will be observed that at the moment of cessation the board and the springs will have a sudden and very decided motion of translation in the same direction as that in which the springs were last moving, and although the springs were at the time swinging through a considerable arc, all motion will suddenly cease.

This shows, that if a house is in a state of vibration the strain at the foundations must be very great.

It would not be difficult to devise other experiments to illustrate other phenomena connected with the principle of relative vibrational periods, but these may perhaps be sufficient to show to those who have not considered this matter, its great importance in the construction of buildings. Perhaps the greater portion of what I have here said may by many be regarded as self evident truisms hardly worth the trouble of demonstration. Their importance, however, seems to be so great that I hope that their discussion has not been altogether out of place.

In putting up buildings to resist the effects of an earthquake, besides the idea of making everything strong because the earthquake is strong, there are several principles which, like the one just enunciated, might advantageously be followed, which as yet appear to have received but little attention.

For instance, we observe that the archways over doors and windows which we find in earthquake countries are in no way different from the archways put up in countries free from earthquakes. As examples of these archways we may take those in the Ginza in Tokio, or those of Calabria as figured by Mr. Mallet in his treatise on the Neapolitan earthquake. The main feature in all such archways is that they are built to withstand a vertical pressure. The effects of an earthquake, however, are stresses applied more or less horizontally, and therefore those archways which had an entrado

curved down into the supporting buttresses would evidently be better able to resist the strains which are imposed upon them than those where the arches spring at an angle from their piers.

Another point worthy of observation to which my attention was first called by my late colleague Mr. Perry, is that the system of placing openings like windows and doors in a building vertically above each other, makes the face of such a building, when acted on by horizontal strains and stresses, likely to give way in such a line, because it is, as compared with the rest of the wall, a vertical line of weakness.

To obviate such a feature, if the artistic appearance of the building would not be violated, such lines of openings might be placed along and parallel to diagonals. In this way so far as horizontal forces were concerned, there would be no special line of weakness upon which they could exert themselves, and the face of the building would have a uniform strength throughout.

In Yokohama the chief source of destruction seems to have arisen from causes somewhat similar to those illustrated in the first seven of the experiments which have just been quoted. The most noticeable kind of destruction was the overthrow of chimneys partly due to the want of good cement or mortar, but chiefly due to a want in synchronism in its period of vibration with that of the house through which it passed. In cases where chimneys stood alone they seemed to have withstood the effect of the shock. Had the chimneys of the houses on the bluff passed through the roofs of the buildings to which they were attached, having on each side of them sufficient play, instead of being in contact with such roofs I am inclined to think that, notwithstanding the bad cementing materials which seem in many cases to have been used to bind their parts together, they might have remained standing. If, however, chimneys must of necessity come in contact with the building it would be necessary to bind them in such a manner, that their upper parts could not vibrate in their own period.

Closely connected with what we have been saying with regard to the fall of chimneys, is the falling of tiles. The houses which lost the greater number of tiles appear to have been those with the steepest pitch, and those where the tiles were simply laid upon the roof and not in any manner fastened down. It would seem that destruction of this sort might to a great extent be obviated, by giving the roofs a less inclination, and fixing the tiles with nails. It was also noticed that the greatest disturbance amongst the tiles was upon the ridges of the roofs. Destruction of this sort might be overcome by giving especial attention to these portions during the construction of the roof.

b. – DESTRUCTION DUE TO TOPOGRAPHICAL POSITION.

In almost all earthquakes which have occurred where buildings have been damaged, it has been observed that buildings occupying certain positions have escaped whilst others have suffered. In some cases it has been the houses which were situated on the plains which suffered the most severely, whilst at other times it has been those which were situated upon the hills. At the time of the earthquake at Wellington, New Zealand, in 1855, the greatest destruction took place upon the sides of the hills, and it was least in the centre of the plains. In the last destructive earthquake which visited Yedo, the chief destruction I am told took place in the valleys. In the earthquake about which we write the chief destruction seems to have taken place upon the top of the hills or else close to their base.

To any one who walked through Yokohama on the morning after the earthquake, that different effects had been produced in different places which were at no great distance from each other was very clearly evident. Generally speaking, out upon the flat ground in the settlement at a distance from the bluff, the destruction of chimneys was comparatively small, whilst at the foot of the bluff and upon the top of it, there were but few buildings which had escaped. From the manner in which all the grave stones lying near to the edge of steep declivities had been moved, whilst those which were further

back were not disturbed, it seemed that it was near to the edges of the bluffs that the movement had been the most violent.

Some of the more obvious reasons why the intensity of earthquake motion should vary with the contour of the ground are as follows:—

1st.—If an earthquake wave is passing through ground the surface of which is level, so long as this ground is homogeneous, as the wave travels further and futher we should expect its energy to become less and less, until, finally, it would insensibly die out. If, however, we have standing upon this plain a mountain, judging from Mr. Mallet's remarks, this mountain would be set into a state of vibration much in the same way as a house is set in vibration, and it would tend to oscillate back and forth with a period of vibration dependent upon the nature of its materials, size, and form. The upper portion of this mountain would, in consequence, swing through a greater arc than the lower portion, and buildings situated on the top of it would swing to and fro through a greater arc than those which were situated near its foot. This explanation why buildings situated on the top of a mountain should suffer more than those situated on a plain, is one which was offered by Mr. Mallet when writing of the Neapolitan Earthquake, who tells us that towns on hills are "rocked as on the top of masts," and if we accept this explanation it would, in fact, be one reason why the houses situated on the Bluff at Yokohama suffered more than those situated in the settlement. I offer this explanation on account of the great authority it claims in consequence of its source. For my own part, I do not clearly see how the statement is supported,—different portions of the mountain receiving momentum in different directions at different times.

2nd.—When a wave of elastic compression is propagated through a medium, we see that the energy of motion is being continually transmitted from particle to particle of that medium. A particle in moving forwards meets with an elastic resistance of the particles towards which it moves, but overcoming these resistances it causes these latter particles to move, and in turn to transmit the energy to others further

on. So long as the medium in which this transfer of energy is continuous, each particle has a limit to its extent of motion dependent on the nature of the medium. When, however, the medium which we will suppose to be the earth is not continuous, but suddenly terminates with a cliff or scarp, the particles adjacent to this cliff or scarp having no resistance offered to their forward motion, are shot forward and consequently the ground here is subjected to more extensive vibrations than at those places where it was continuous. This may be illustrated by a row of marbles lying in a horizontal groove; a single marble rolled against one end of this row will give a concussion which will run through the chain, like the bumping of an engine against a row of railway cars, and as a result, the marble at the opposite end of the row being without support will fly off. Tyndall illustrates the same thing with his well known row of boys standing in a line with their arms stretched out and their hands resting upon the shoulders of the boy before them. A push being given to the boy at the back, the effect is to transmit a push to the first boy, who, being unsupported, flies forward.

In the case of some earthquakes, most disastrous results have occurred which seem only to admit of an explanation such as this. A remarkable instance of this kind is mentioned when the great earthquake of 1857, "swept along the Alps from Geneva to the East North East, and its crest reached the edge of the deep glen between Zermatt and Visp. Then the upper part of the wave-movement a thousand or two thousand feet in depth from the surface, came to an end; the forward pulsation acted like the breaker of the sea, and heavy falls of rock encumbered the western side of the valley."

The Bluff at Yokohama consists, as has already been stated, of a plateau cut through in various directions by deep valleys the sides of which are often very steep, and here and there very nearly perpendicular. The general configuration of the ground is, in fact, eminently fitted for the exhibition of phenomena of this description. The degree in which they will be manifested will to a large extent be dependent upon the angle of emergence at which the shock may be supposed

to emanate, and the slopes of the various scarps. So long as the wave which we will imagine is travelling E. to W. is almost horizontal, it will produce much the same effect upon a bluff facing east as it would upon a bluff which was facing west. If however, the angle of emergence of the wave was for instance 45° it would be much more likely to produce serious effects upon the western face of a bluff it was traversing than it would upon the eastern. What we have here said, has been exemplified in other earthquakes than the one we write about, and although no definite measurements have been made giving the relative intensities of a shock upon the edge of a cliff as compared with situations removed from such a position, we feel certain that the differences between them will be great. The lesson to be learnt by those interested in building houses in earthquake shaken countries from the facts which have been placed before us by this earthquake relative to the points which are here considered, is one which certainly demands serious consideration.

3rd.—If a mountain stands upon a plain through which an elastic wave is passing which is almost horizontal, the mountain is, so to speak, in the *shadow* of such a wave. If we only consider the normal motion of this wave we see that the only motion which the mountain can obtain will be a wave of elastic distortion produced by a shearing force along the plain of the base. Should, however, the wave approach the mountain from below and emerge into it at a certain angle, only the portion of the mountain on the side from which the wave advanced could remain in shadow whilst the portion on the opposite side would be thrown into a state of compression and extension. Portions in shadow, however, would be subject to waves of elastic distortion. In a manner similar to this we may imagine that certain portions of the bluff so far as the advancing wave was concerned, were in shadow, and thus saved from the immediate influence of the direct shock. A hypothetical case of such a shadow is shown in the section illustrating the contour of the ground at Yokohama (Fig. 10.) The situation which might be in the shadow of one shock however it is quite possible might not be in that of another. We must also remember that a place

in shadow for a direct shock might be affected by reflected waves and also by the transverse vibrations of the direct shock. These effects are over and above the effects produced by waves of elastic distortion just referred to.

c.—Destruction due to the Nature of the Underlying Rocks.

I will now pass on to the consideration of the destruction which occurred in Yokohama and Tokio and its relation to the nature of the underlying rocks.

That the nature of the ground on which a building stands has much to do with the severity of the blow it receives is a fact which has been often demonstrated. In certain parts of South America there appear to exist certain tracts of ground which are practically exempt from earthquake shocks, whilst the whole country around such an area may be violently shaken. It would seem as if the shock passes beneath such a district as water passes beneath a bridge, and for this reason these districts have been christened "bridges."

This phenomenon appears to depend upon the nature of the underlying soil. When an elastic wave passes from one bed of rock to another of a different character a certain portion of the wave is reflected whilst a certain portion of it is transmitted and refracted, and "bridges" we may conceive of as occurring where the phenomenon of total reflection occurs. In Yokohama and Tokio we have no reason to believe that total reflection occurred at any point, but it would seem that something approaching it may have happened at Mayebashi. When a wave is reflected it gives rise to a series of return waves, which may interfere with the series of waves advancing towards the surface of reflection. This interference produces more or less disturbance at and about the point where it takes place. If this disturbance is great, buildings on the surface may seriously suffer, whilst those which are distant from such a point of disturbance may suffer but little. From this we see that we may have destruction occasioned by the interference of waves. Another cause of destruction is due to placing a building on foundations which are capable of receiving the full effect of a shock and transmitting it to the buildings standing on them. We have

here then two principal explanations each dependent upon the geological nature of the ground which may shew us why destruction is more marked in one locality than it is in another. These I will discuss in relation to the effects observed in Yokohama and Tokio.

1st.—Destruction as due to the Interference of Waves.

Referring to the section of the ground at Yokohama (Fig. 10) it will be seen that both the settlement and the bluff stand upon beds of gravel capping horizontal beds of grey tuff. The gravel of that portion of the settlement on the seaboard originally formed the line of a shingle beach. That portion of the settlement back from the sea stands upon ground which was originally marshy. In the central portions of the settlement this bed of gravel is very thick, perhaps 100 feet or so, but as you near the edge of the bluff it probably becomes thinner until it finally dies out upon the flanks of the scarps.

On the top of the bluff the beds of gravel will in every probability be generally thinner than they are upon the lower level. The beds of tuff, which is a soft grey coloured clay like rock produced by the solidification of volcanic mud, appear, when walking on the seaboard, to be horizontally stratified. If there is a dip inland, of which however I have not seen any evidence, it is in all probability very slight. Here and there the beds are slightly faulted. Taken as a whole we may consider these beds as being tolerably homogeneous and an earthquake in passing through them would meet with but little reflection or refraction. At the junction of these beds with the overlying gravels both reflection and refraction would comparatively be very great.

On entering the gravel, as the wave would be passing into a less elastic medium, the direction of the wave would be bent towards the perpendicular to the line of junction, and the angle of emergence at the surface would consequently be augmented. At the surface certain reflections would also take place, but the chief reflections would be those at the junction of the tuff and the alluvium.

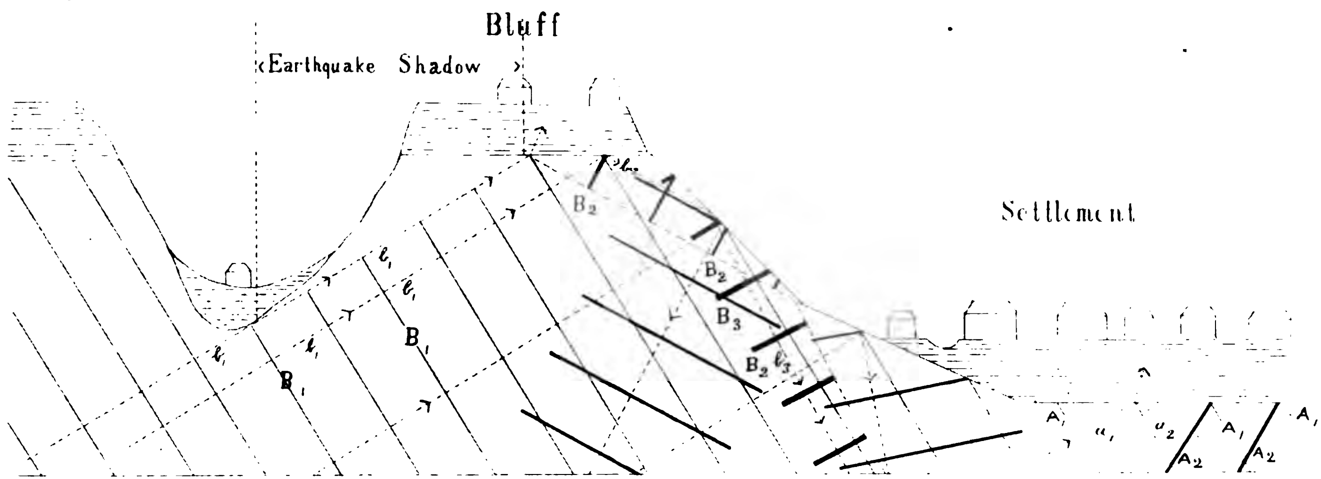


fig.10. Hypothetical Section at Yokohama.

Under the settlement it is probable that all the reflections which took place would be single. Thus wave fronts like A_1 advancing in a direction parallel to the line a_1 would be reflected in a direction a_2 and give rise to a series of reflected waves A_2. These are shewn by thicker lines. Similarly all the neighbouring waves to the right and left of A_1 would give rise to a series of reflected waves. If the lines drawn representing wave fronts are districts of compression then where two of the lines cross each other there would be double energy in producing compression. Similarly, districts of rarefaction might accord, and again compression of one wave might meet with the rarefaction of another and a neutralization of effect take place. A diagram illustrating concurrence and interference of this discription is given in Le Conte's *Elements of Geology*, page 115. The interference which has been spoken of, however, is not the greatest which would occur. The greatest would probably be beneath the bluff and the scarps which run down to join the level ground below. This would be the case because it is a probability that there might not only be cases of interference of single reflected waves, but also of waves which had been not only twice but perhaps thrice reflected. For example, a wave like B_1 (which is parallel to A_1 of the first supposition) advancing in a direction parallel to b_1 might be reflected along the line b_2 giving rise to waves like B_2 which in turn might be reflected along b_3 giving rise to waves like B_3. The number of districts where there would be concurrence and interference would in consequence of the number of times waves might be reflected be augmented. Here the violence of the shock would at certain points be considerably increased but as a general result energy must be lost, so that even if some of the reflected waves found their way into the portion we have regarded as being in shadow their intensity would not be so great as if they had entered it directly.

2ND.—DESTRUCTION DIRECTLY DUE TO THE NATURE OF THE GROUND FORMING THE FOUNDATION.

From the short description which has been given respecting the geological nature of the ground at Yokohama it will be seen that the settlement stands either upon a thick bed of

shingle or else of mud. As this nears the edge of the Bluff it becomes thinner. On the top of the Bluff the shingle where it occurs is generally thinner than it appears to be below.

Now it would seem that beds of shingle, earth, and silt, might be regarded as a pad lying between the buildings which stand upon them, and the harder rocks beneath. The effects of this pad would be twofold. First it would reflect a certain portion of an advancing wave, and secondly by its elasticity and the internal motion of its parts it would tend to absorb rather than transmit that portion of the blow which entered into it. In this latter respect a loose foundation might act something like the buffer of a railway carriage. It must also be observed that the shock on entering loose material would have its waves more crowded. It is also possible that a long line of buildings might rest on more than one wave during the shock. Because in the settlement the pad of loose material was thickest, is probably one of the reasons why the effects of the shock were comparatively small. Where the plain joins the Bluff the pad was thin and the disturbance beneath the buildings was in consequence very great. This was augmented by the interference of waves. On the top of tho Bluff the pad was in places thin and in places thick, but the disturbance due to wave interferences was great and as a consequence we find that the destruction was also very great.

It may be remarked that destruction occasioned by an earthquake has often been observed to have had a maximum at the junction of a plain with a mountain, and as an explanation of the phenomenon in addition to what I have said it has been suggested that a slight shaking down of the loose strata resting on the slope may have taken place.

I have now given what appear to me to be some of the principal phenomena which were observed in connection with the destruction of buildings, and at the same time I have ventured to offer explanations for the same. If my explanations are correct then the more important lessons which appear to be indicated to us are briefly as follows.

1.—Let all portions of a building have their natural periods of vibration nearly equal.

2.—If it is a necessity that one portion of a building should have a very different period of vibration to the remainder, as for instance a brick chimney in a wooden house, it would seem advisable either to let these two portions be sufficiently free to have an independent motion, or else they must be bound together with great strength.

3.—Avoid heavy topped roofs and chimneys. If the foundations were free the roof might be heavy.

4.—In brick or stone work use good cement.

5.—Let archways curve into their abutments.

6.—Let roofs have a low pitch and the tiles, especially those upon the ridges, be well secured.

7.—From the effect observed in the last earthquake it would seem that a building placed upon a plain is in a less dangerous position than one which is placed either at the junction of a hill and plain, or upon a hill.

8.—The most dangerous position for a building will generally be upon the edge of a scarp or cliff. This danger will be intensified if this edge is on that end of the bluff at which the wave makes its exit.

9.—Buildings placed near the junction of strata of very different elasticities are in a dangerous position.

10.—Buildings standing on thick beds of soft material are in a better position to with-stand the effects of a shock than those which are built upon solid rock.

From what has been said a few more inferences might be drawn but these appear to be the most important. The study of the damage produced by earthquakes upon buildings is as interesting as it is extensive. Here I have confined myself to the discussion of the phenomena which were observed in one special earthquake. At a future time I hope to write more generally upon this subject.

IX. Cracks in the Ground.

The only cracks which were made in the ground with which I am acquainted, were some in the road which runs near to the cliffs overlooking the bay at the eastern end of the bluff. One of these cracks which ran parallel with the road was about 25 yards long, 1 or 2 inches in breadth, and 6 feet or

more in depth. As this portion of the road was expected to fall seawards it was railed off. We may regard this crack as a feeble repetition of the phenomenon which occurred in the valley of Zermat which has already been spoken about. I may remark that in the spring of 1878 a somewhat similar crack to that on the bluff at Yokohama was formed in the ground behind the old Gaimusho in Tokio

X. Projection of Bodies.

Closely connected with the velocity of an earth particle we have the distances to which various bodies were thrown. On the morning after the shock examples of plaster thrown off the sides of houses, and tiles from roofs, were exceedingly numerous. The only matter of special note connected with this as seen in Tokio appeared to be, that it was chiefly from those sides of houses which were broad side on to the shock that materials had been thrown down. As an example of these I may mention that a "godown" (fire proof store house) built with a wooden frame work covered with mud, and on the outside plastered, standing at my garden gate, lost the whole of its eaves upon the northern side. With the eaves the adjacent portion of the roof and the upper part of the wall also came down. The vertical height which this material fell was about 20 feet, and the horizontal distance from the foot of the building to the middle of the heap of debris was about 6 feet. Examples of this kind were very numerous, but as the distance to which the material was thrown depended chiefly upon the vibration of the house, and therefore seemed likely to be of but little value in telling us anything about the movement of the earth, I did not make any accurate records of these disasters.

The same may be said about tiles which fell from roofs. Several fell from the roof of my own house, but as the distance to which they were thrown depended partly upon the swing of the house, and partly upon the fact that they had rolled or slided some distance before being clear of the eaves, the measurements of such distances would be but of little value in determining anything about the velocity of the shock.

Altogether I may say that I have but few records relating to projection which will be of use in making calculations relating to the shock.

The following three records I received from Yokohama.

1.—The corner stone of a chimney fell 35 feet vertically and 20 feet horizontally towards the S.E.

2.—The top of a Japanese stone lantern fell 6 feet vertically, and was projected 4 feet towards the East.

3.—Some vases were projected from N. to W. to a horizontal distance of about 6 feet.

Of the falling of objects like vases, bottles, etc. the examples as one might suppose were very numerous, but of measurement made upon the projection of bodies which had been thrown by the shock, and not by the natural vibration of the support on which they stood the examples are very scarce.

XI.—General Character of the Movement.

From what has been said respecting the direction of the shock some of the peculiarities of the movement will have been inferred. Reference has been made to a reflected shock, to an apparent twisting motion, and to the succession of different periods of intensity as indicated by instruments.

Part of what I have to say is founded upon matters of opinion and part upon observations. As it is only from a proper understanding of the character of these earth movements that we can hope to determine the nature of their origin. I will give in detail all that seems to be connected with them.

Observations in Yokohama.

In Yokohama as in other places different persons describe the motion in very different manners. In some cases this will be due to differences in opinion, while in others to actual difference in their experiences dependent upon their situation.

The simplest description of the movement which I have received is that of a slight shock immediately followed by a severe one. Another writer says that there were two shocks

quickly succeeding each other and that the house did not simply shake but oscillated. This is confirmed by several other observations as will be seen from the following quotations :—

1.—The shock commenced with a swaying movement which was immediately followed by a wrench or circular motion. After this there was a swinging motion in the house so great that it was necessary to balance oneself whilst descending the stairs.

2.—There were two shocks the second one being the stronger. The house in which the observer was situated which was a brick one, seemed to dance, to twist, to screw, and to wriggle. Before the motion ceased the house was oscillating. It would seem as if the shock came up from below.

3.—There was a twisting three cornered sort of a movement.

Another observer says from the manner in which window catches were drawn it would seem as if there had been much upward movement.

The experiences of those who were on board ship at the time were extremely various. On some ships like the *Courier* and the *Akitsushima-maru* the shock does not appear to have been felt at all, whilst on other ships the movement was so severe that it was imagined that the vessels, were aground. On board the *Takachiho-maru* a rough movement was felt as if the vessel's bottom was surging over a large tight hawser.

Observations in Tokio.

One gentleman writing from Tokio speaks of having distinctly felt *three* shocks, the last one being the most severe.

Another says the house rocked like a ship in a gale.

At Shinagawa the motion was described as being at the heaviest part, similar to that of a small boat tossed about amongst heavy tide rips.

This latter observation was made upstairs in a Japanese house. Another observer under similar circumstances describes the motion as being so strong that he had twice to

shift his position in order to secure a better footing. He found that he could keep himself the steadiest when looking westward, just as we would be steadier in a rolling ship when looking towards the bows.

In one brick house the motion was described as being such that you were induced to imagine that the walls would suddenly give way and close in upon you. In another brick house, however, the motion was described as being a swinging of the whole building but without the rattling which you usually get with the smaller shocks.

From these observations we see that there were at least two periods when the motion appeared to reach a maximum and also that the motion was sufficiently great to set up an oscillation in a building, this probably rocking back and forth with a slow period of its own. From my own experience I should say that the shock commenced gently, it then reached a maximum, to some extent died away, then reached a second maximum, from which it finally subsided as gently as it had begun.

Motion as felt by persons out of doors.

One gentleman with whom I conversed told me that finding his doors were jammed by the shock he escaped through the window and immediately fell with his back upon an earth bank in the garden. Whilst there he says that he distinctly felt a palpitation in the ground.

This is the only record which I have of persons who were out of doors at the time of the shock experiencing any motion. Several persons heard the noise of falling chimneys and a general roar, probably due to the breaking and creaking of timbers. This made them suppose that an earthquake was taking place, but they themselves did not feel the slghtest motion.

Several persons who were travelling in jinrickshaw at the time of the shock reached home unaware of the fact that there had been a shaking. This I may remark was in Tokio.

Personally, I do not remember excepting upon one occasion when skating, ever having been aware of a shock having taken place whilst I was out of doors.

Observations like these I think clearly show us that an earthquake which would almost shake a city down might if we were dwelling in tents or outside brick or wooden dwellings be on many occasions passed by almost unnoticed. Remarks bearing upon this point will be found where I speak of the sounds which accompanied the earthquake.

Character of Motion as given by Instruments.

From the observations at Yamato Yashiki it would appear there had been three shocks, the times of which have already been given. The two intervals between these three shocks are 57 seconds and 2 minutes 3 seconds respectively. As the second shock is reported as having been the larger of the two we can hardly regard it as being the reflection of the one which preceded it. It is, however, quite possible for the third to have been a reflection of the second. If we imagine the shock to have travelled at a rate of about 1 mile in five seconds, in the interval between the first and second shocks, it may have travelled a distance of about 24 miles or suffered a reflection at some point about half this distance from Tokio.

Such a supposition would agree with the evidence which has already been adduced to show that there may have been shocks in two directions, one of which we suggested as possibly being the reflection of the other.

The other explanation of this fact would be that the earthquake had been made up of three successive blows such for instance as we might imagine to occur during the formation of a fault or fissure, and that each of these had sent out its vibrations into the surrounding districts.

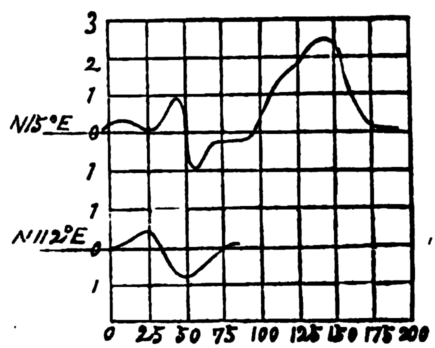
The nature of the movement as indicated upon a smoked glass plate which during the first part of the earthquake moved beneath a pointer depended from the bob of a heavy pendulum about 25 feet in length, was, so far as it extended, extremely satisfactory. The length of this plate is about 9 inches but the length of the mark made upon it, is only about 7½ inches or more accurately 190 millimeters. The time taken to travel this distance as near as I am able to measure it, was about 3 seconds and during this time only

two waves were drawn. Had the plate been somewhat longer and moved more slowly a registration of the whole earthquake might possibly have been obtained.

The shape of these waves may be plotted from the following table.

The central column gives distances in millimeters measured along a strait line 190 mm. in length drawn from one end of the curve to the other. The direction of this line is about 15° E. of N. The left hand column gives distances from this line to points on the curve measured to the left. The right hand column gives similar distances measured to the right.

0	0	0
.25	5	0
0	10	0
0	30	0
1	45	0
0	50	0
0	55	1
0	65	1
0	68	.5
0	80	.5
0	95	0
0	100	0
1	110	0
2.5	150	0
1	155	0
0	175	0
0	190	0



(Fig. 11)

In Fig. 11 this curve which is the upper one is so plotted that the total length of the curve has been divided by five whilst its amplitude has been multiplied by five.

The latter portion of this curve measured horizontally is somewhat exaggerated, the plate having been actuated by a falling weight turning a roller which winding up a thread pulled the plates along.

A second plate moving at right angles to the one described, which was drawn along by a thread from the same roller, gave a curve from which the lower part of Fig. 11 has been drawn. It represents a length of 85 milliemeters and was plotted from the following measurements which have the same meaning as the measurements just given.

0	......	0	......	0
0	......	5	......	0
.25	......	10	......	0
0	......	15	......	0
.5	......	20	......	0
0	......	32	......	0
0	......	45	......	.75
0	......	72	......	0
.25	......	85	......	0

Looking at the lower of these two figures it would seem that rather than an earth particle having vibrated back and forth with a regular motion it had been moved by sudden jerks or kicks. From similar diagrams obtained from previous earthquakes and also from succeeding ones it would seem that such is more likely to be the general character of the earth's motion rather than that of a series of regular vibrations.

If the crust of the earth received a single blow and thus were set into a state of vibration which vibrations gradually died out, it is easy to conceive that a series of regular curves might be drawn upon a plate moving with the earth which plate was marked upon by a steady pointer.

So far as can be judged of from what we feel at the time of an earthquake and from the irregular curves which an earthquake writes upon moving plates, it would seem as if the motion was compounded of a series of blows or jars struck in such quick succession that all regular vibrations appear to be destroyed. Now and then perhaps an earthquake

may be experienced which is like the single blow and with suitable apparatus the resulting quivers may be registered. These, however, so far as my experience has gone will prove themselves to be the exception rather than the rule. More delicate apparatus wherewith to register and magnify these motions may possibly lead us to more definite results.

Amplitude and Velocity of an Earth Particle.

The greatest amplitude of the two jolts which I have registered are respectively 1 and 1.25 millimeters. The first of these was made whilst the plate moved a distance of 10 millimeters between 45 and 55. Assuming that the plate took 3 seconds to move 190 millimeters, the motion being so slow on account of frictional resistances, duly considering acceleration, the time to move from 45 to 55 would be about .153 second. That is to say at this period an earth particle had a maximum velocity of about 21 $^{mm.}$ per second.

At the time of the second jolt the maximum velocity when calculated in a similar manner would be about 22.5 millimeters per second.

During other portions of the shock it is very possible that the velocity may have been much greater than this.

Observation with a swinging Pendulum.

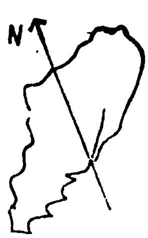
As interesting an observation as the above is one which was made with a heavy pendulum with a pointer, which at the time of the earthquake was set swinging over the surface of a smoked glass plate.

When this pendulum, which is about 18 feet long and carries a bob of 20 lbs, is swinging, it takes, as deduced from a number of observations, about 2 seconds to make a single swing, the pointer at the time tracing out a number of ellipses on the smoked surface of a glass plate. At the time of the shock the pendulum after making a short line on which there are two irregular jolts, the respective lengths of which are about 3 and 8 millimeters, described five ellipses.

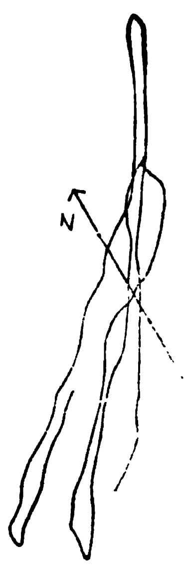
The total length of these is about 2 inches, and the total breadth half an inch. At the fifth swing the pointer passed

over the edge of the glass plate and dropped out, so that markings then ceased to be made. The time taken to make these ellipses must have been about 10 seconds. The irregularities on them, which may be described as a number of ripples, are such as can be produced by shaking the table whilst the pendulum is swinging or by a wobbling motion in the pendulum itself. As I do not see how wobbling could have been set up I am inclined to think that they were produced by the earthquake having caused a shaking in the table. In the smaller of these ellipses, which means the ellipses which were formed when the pendulum was moving at the lowest velocity, the ripples are numerous and crowded together, whilst in the larger ellipses which were formed when the swing of the pendulum would be at its quickest, the ripples are drawn out into gentle undulations.

In consequence of the manner in which these ellipses intersect each other and the fact of their being so irregular in themselves it is an exceedingly difficult matter to separate them from each other by simply glancing at them. To remove this difficulty I have represented four of them separately in Figs 12, 13 and 14.



(Fig. 12.)



(Fig. 13.)

(Fig. 14.)

These drawings, which were made by carefully tracing a photograph, of the smoked glass plate, are of the natural size. Their relative positions would be obtained by superimposing them on each other so that the line N. S. which is north and south was coincident in each of them.

Even if we take the very largest motions which seem to be indicated upon these figures, such as the whole width of the upper end of Fig. 12, we see that the motion of the plate beneath the pointer has not exceeded 10 millimeters.

From the ripples in Fig. 12 it would seem that the greatest motion had not exceeded 2 or 3 millimeters, a result which agrees fairly well with the results obtained from the sliding plates.

Looking at the left side of Fig. 12, 8 ripples may be counted; on the right side, which is incomplete, there are about six. On the left side of Fig. 13 there also appear to be about 6 ripples.

This would seem to tell us that there must have been about three vibrations per second. From this it follows that if the amplitude of a vibration was about 1 or 1.5 millimeters as it seems to have been, then the distance travelled by an earth particle would be about 12 or 18 millimeters per second. This means a maximum velocity of about 19 $^{mm.}$ or 28 $^{mm.}$ per second. These curves it must be observed were probably made during a different portion of the shock than those previously discussed which were certainly made near to the commencement of the movement.

As the whole of these latter results may be described as being accidental ones, and therefore subject to errors difficult to eradicate, I will not lay great stress upon them.

They have, however, been so suggestive of a method which may be employed that I am at the present moment arranging one of my long pendulums so that at the time of an earthquake it shall be set off in an elliptic motion. In this manner I hope to obtain a repetition of what hitherto has been an accident. Owing to the length of the pendulum, the method in which it is supported, and the fact that it will be a heavy body in motion, so far as not being affected by the

earthquake it ought to combine the advantages of the long pendulum and those of the gyrostat.

For the Neapolitan earthquake of 1857 Mr. Mallet gives maximum velocities for the motion of particles as being from 9.78 to 21.23 feet per second, the mean being 12.039 feet per second. This velocity appeared to decrease as the distance from the seismic vertical increased.

The amplitudes were from 4.75 to 2.5 inches, the greater amplitudes increasing as the distance from the seismic vertical. Taking 3 inches as an average for this amplitude and computing from the average maximum velocity we see that the average number of vibrations must have been 7.8 per second.

The horizontal motion of an earth particle as given by the apparatus of Dr. Wagener, which observations have been kindly forwarded to me by Mr. Knipping, was approximately 21 millimeters. Mr. Knipping tells me that because a portion of the apparatus broke this measurement must be regarded as a lower limit.

As I know from personal observation that during this shock pendulums from 2 to 30 feet in length put up in various ways, some attached to flexible roofs, and some to stiff frames, swung violently, I am inclined to think that the high measurement just recorded may have been due to a similar cause.

In Yokohama I met with an interesting observation indicating to us something about the amplitude. This was at a house upon the Bluff overlooking the sea. The house was built of successive tiers of oblong blocks of stone, the joints between the stones being vertical. In consequence of the earthquake the joints in many cases opened, there having been a lateral shifting of the stones. In some cases the joints of several stones in a tier had been opened, whilst in another tier it was only one joint which had separated.

The noticeable point, however, was that it would appear as if the average width of all the cracks taken in any one tier was about equal to the average width taken in any other tier, or, in other words, the sum total of the width of openings in one tier was equal to the sum total of the width of open-

ings in another. One of the largest openings which I measured was $\frac{5}{8}$ of an inch in width. In another house built of brick the width of the crack was only about $\frac{1}{4}$ inch.

In the Calabrian earthquake of 1857 it was from observations of this sort that Mr. Mallet deduced the measurements which he has given for the amplitude of an earth particle. He himself, however, does not seem to place much reliance in them. Reckoning in the same way we might say that this house gave us evidence of a movement of $\frac{5}{8}$ of an inch or about 21 millemeters, a measurement it will be observed coinciding with that given by Dr. Wagener's apparatus. I myself am inclined to think that the sudden jerk with which these bodies have been moved tends to throw them farther than the actual distance through which the jerking motion itself extended, and therefore that these results are somewhat exaggerated.

The extent of motion may also be judged of by the fact that in Yokohama a lamp with a supporting rod 8 ft. in length swung through an arc of 15 or 16 inches, whilst another with a support of 6 ft. swung through an arc of 2 feet.

In Tokio, at the German Legation, a lamp with a 9 ft. support swung through a distance of 2 feet, and at several houses Kakemono (long flat pictures) were observed to oscillate whilst hanging on a wall through distances of from 12 to 18 inches.

The swing of objects like these, however, would largely depend upon the oscillation of the building in which they were suspended and not directly upon the movement of the earth.

Another method of arriving at the maximum velocity of the wave would be an application of the formula of Professor Haughton as used by Mr. Mallet when working on the Neapolitan earthquake, in conjunction with the few observations which have been given when speaking of projection or the overturning of bodies.

If V be the velocity of shock.

b the height though which the centre of gravity of a body descended.

a the horizontal distance traversed by the same centre.

e the angle of emergence.

Then for projection due tothe first semiphase of the wave.

$$V^2 = \frac{a^2 g}{2 \cos^2 e \, (b - a \tan e)}$$

For projection by the second semiphase.

$$V^2 = \frac{a^2 g}{2 \cos^2 e \, (b + a \tan e)}$$

Farther on it will be seen that I have taken 6° or 18° as being the most probable value for e. Taking the case of the Japanese lantern which, from the direction in which it fell, appears to have been projected by a shock in its first semiphase $b=6$ and $a=4$. Substituting these values in the first of the above equations, first for an angle of emergence of 6°, and then for one of 18°, we obtain as maximum velocities 6.8 and 6.7 feet per second. In a similar manner, by using the remaining data which have been given, analogous results might be arrived at. The discrepancy beteen these results deduced from theoretical considerations, and those obtained from intruments are very great, but I think they are explicable.

My observations made by the sliding plates represent a portion of the shock very near its commencement. As the shock increased in intensity the maximum velocity deduced from my observation is near the minimum of the different velocities with which the shock subsequently moved.

Mr. Mallet makes calculations respecting the velocity of the horizontal component of a wave from the arc through which a pendulum was swung by a single undulation. As it seemed to me that the various pendulums I observed to swing, did so in consequence of the house in which they were suspended gradually commencing to swing, the formula can hardly be applied. The same remarks apply to the records which I have received of the swing of lamps.

For the calculation of the velocity of a wave particle from the overturning of bodies I am also withont very definite observations. What can be said on this subject however, is, that rectangular gravestones with a cross section of about 10 in. and a height of 40 in. resting on stone bases

were not overturned, whilst iron columns in the form of truncated cones with a section at the ends of 12 and 73 millimeters and 160 millimeters high, were thrown over.

For the overturning of a rectangular parallelopiped Mr. Mallet uses the formula

$$V^2 = \tfrac{4}{3} g \times \frac{a^2 + b^2}{a^2} + \left\{ \left(a^2 + b^2 \right)^{\frac{1}{2}} - a \right\}$$

where a=the altitude, b=side of the base.

Substituting for a and b the values given for the dimensions of one of the smallest gravestones we find that the lowest velocity necessary to overturn such a stone would be about 4 ft. per second. Supposing such a stone to have had a basal section of 12 inches the height remaining the same, the required velocity would have been almost $2\frac{1}{2}$ feet per second.

From the manner in which stones of these dimensions were shaken and moved, it is probable that they must at some period or other have been nearly overturned, and that if we regard this overturning tendency to have acted like a sudden blow then we may say that the velocity of the shock must at one time have been very nearly two feet per second.

The general formula used by Mr. Mallet when discussing the overthrow of various bodies is

$$V^2 = g \times \frac{k^2}{a} \times \frac{1-\cos f}{\cos^2 f}$$

Where a=distance in feet from the edge over which the body turns to the centre of gravity, f is the angle between the line a and the vertical, k is the radius of gyration.

This formula has been applied by my colleague, Mr. Thomas Gray, to the overturning of the truncated iron cone as follows.

Let h=height of frustrum.

R=the radius at the top.

r= " " bottom.

Then the square of the radius of gyration round a tangent to its base is

$$K^2 = \frac{\int_0^h \left(x\frac{R-r}{h}+r\right)^2 \left\{x^2+r^2+\frac{1}{4}\left(\frac{x(R-r)}{h}+r\right)^2\right\} dx}{\int_0^h \left(x\,\frac{R-r}{h}+r\right)^2 dx}$$

$$= \frac{3h^2(R-r)}{R^3-r^3}\left\{\frac{(R-r)^2}{5}+\frac{R-r}{2}+\frac{r^2}{3}\right\}+\frac{3}{20}\frac{R^5-r^5}{R^3-r^3}+r^2$$

For the case in question substituting $r=6$, $R=18.5$, $h=155$, as a result $k^2=10{,}630$ mm.

Inserting this value for k^2 in the general equation the velocity resulting from this calculation is about 58 millimeters per second.

This result accords pretty closely with the result obtained from the moving plates, and it is probable that like this latter it indicates the velocity at the commencement of the motion. The velocities of 6 and 7 feet obtained from calculations based on the falling of a stone lantern, I am inclined to think are much too high, owing to the want of a true knowledge of the actual conditions, it, for instance, being quite possible that the upper part of the lamp when falling may have struck upon the edge of the projecting shelf on which such lamps usually rest, and bounding off from which has had its distance of horizontal projection considerably augmented.

The limiting velocities we may thus say were, at the commencement of the shock in Tokio about 50 millimeters (2 inches) per second, and during the severest portion of the shock in Yokohama nearly 2 feet per second.

In many cemetaries like the one at Atago-Yama in Tokio I have not the slightest doubt but that many of the smaller gravestones were actually thrown over. To distinguish these from the hundreds and I think I may safely say thousands of others which have been knocked down for the amusement of idle visitors, is a difficulty which can be only appreciated by those who are familiar with the confusion of ruin which prevails in the cemetaries like those I speak about. The stones which are most easily pitched over are

those which are in shape something like an elongated egg standing on a truncated end. A few of this form which were recently erected were possibly thrown over, but to distinguish them from the hundreds of others amongst which they have tumbled, is too uncertain an undertaking for the results obtained therefrom to be of any value.

When speaking of the overturning or projection of bodies I have unreservedly used the same formulæ as those employed by Mr. Mallet. These formulæ appear to be based on the supposition that a body is overturned or propelled by the sudden acquisition of momentum,—the earthquake acts, in fact, as if it struck a blow. In some cases this may possibly be a just assumption, but it would seem that cases may occur when we must be on our guard in our application of formulæ based on such a supposition.

In this last shock it would seem that many of the gravestones had been thrown into violent motion without being overturned, and it is not unlikely that they were rocked back and forth with a period partly dependent on their shape. Had the shock been a little more severe the rocking might by the synchronisms of the earth's motion with that of the column caused this latter to have fallen over. In cases like these which will be numerous whenever an earthquake commences gently, the determination of the velocity which overturned a body will to a great extent depend upon the principle of relative vibrational periods already spoken about. These remarks may help to explain the differences in the calculations for maximum velocity.

When speaking of the area over which the shock was felt the size of this area was used as a means of comparing the energy of this shock with shocks like those which have been felt at Lisbon, Naples, and other places.

Another method of making such comparison would be to compare together the motion of an earth particle at equal distances from the origin of two such shocks. Thus in the Neapolitan earthquake of 1857, from Mr. Mallet's researches we find that at a distance of about 16 miles from the seismic vertical the velocity of an earth particle was about 12 feet per second. At the same distance from the seismic vertical

the velocity in this last earthquake was under four feet per second. Comparing these two shocks together according to the squares of their velocities they would be to each other as

144 : 16 or as 9 : 1.

By the other method of comparison, namely, by the square of the radii of the area over which the shock was felt with similar intensity the Neapolitan shock would be to the Yokohama shock as

$140^2 : 50^2$ or about 8 : 1.

These radii represent distances from the origin at which the shock was sufficiently strong to be recorded by seismometers. The comparison might have been made by taking distances at which the shock was just sufficient to slightly shatter buildings.

As a result we see that we may regard the Neapolitan earthquake to have been either 8 or 9 times greater than the Yokohama shock. These great discrepancies are no doubt due to the inequality of circumstances not considered under which these two earthquakes respectively occurred; much for instance would depend upon the relative depth at which these shocks occurred, the configuration of the ground they had to move, and the nature of the rocks. These results must then, like many of the calculations applied to geological problems, only be regarded as a means of giving faint conceptions of things which, being outside one's every day experiences, we should otherwise be totally unable to form any definite ideas about and not to be looked at as absolute and accurate conclusions as we are liable to look at mathematical results.

Vertical Motion.

When speaking about the general character of the movement it was stated that a considerable amount of vertical motion, had been experienced. This was recorded by several machines.

A portion of Dr. Wagener's apparatus indicated a vertical movement of ·56 mm.

Mr. Gray's instrument indicated a vertical motion of about three millimeters. Two spiral springs suspended vertically,

carrying at their lower end a heavy weight which I have been using to detect vertical motion, gave very definite indications.

One of them made of steel wire about 3/8 of an inch in thickness twisted into a spiral about $3\frac{1}{2}$ inches in diameter and 2 ft. long, carrying a weight of about 20 lbs. gave a vertical movement of about 3 mm. This spring makes about 4 vibrations per second. The second spring which makes about 1 vibration per second and is made out of wire about 1/8 of an inch thick, forming a coil 16^{in} long and $2\frac{1}{2}^{\text{in}}$ broad oscillated through a distance of from 5 to 15 millimeters.

Both of these springs were suspended from a rigid frame standing on a stone column.

The self-recording Barograph at the Yamato Yashiki Observatory gave a line indicating a vertical motion of one millimeter. This means that at the time of the earthquake an iron cylinder floating in mercury in consequence of its inertia remained steady whilst the mercury in which it floated was raised up round it one millimeter above its usual height.

An instrument like this, although not constructed for observing earthquakes, ought to give a fair approximation to the true vertical motion. The principle on which it works, I may remark, is similar to that on which Dr. Wagener's recorder of vertical motion works.

Angle of Emergence.

From the various observations which have been given of the horizontal and vertical motion it is an easy matter to calculate the angle at which the shock may be supposed to have emerged. The angle of emergence as calculated from the horizontal and vertical movements as given by Dr. Wagener's appparatus would be about 1°.5′. The horizontal motion which was here given, namely, 21 millimeters, I am inclined to think was too great, and the observations of from three to five millimeters are probably much nearer to the motion which actually occurred. With a vertical motion of 0.56 and a horizontal motion of 3 millimeters the angle of emergence would be 10°.5 whilst if the horizontal motion were 5 millimeters the angle would be 6.° 25. Taking a

horizontal motion of 3 or 5 millimeters with a vertical motion of 1 millimeter as given at the Yamato Yashiki Observatory we obtain an angle of emergence of 18 or 11°. Taking an observation like that of Mr. Gray's or my own on which I may remark I do not put so much reliance as I do upon that made by Dr. Wagener's instrument, where we have a vertical motion of 3 millimeters, the above two angles would, with the same horizontal motions as before, respectively become 45° and 31°. That the angle of emergence was great may be judged of by the angle made with the horizon by cracks in walls. Here then we have as limits for one angle of emergence at Tokio, and I may add Yokohama, as it is situated at about the same distance from the origin, on the one hand 45° and the other 11° 5. When we consider how window catches were drawn upwards in Yokohama, and other phenomena which occurred I do not think we can accept this latter observation.

The most probable deduction appears to me to be one deduced by the combination of the observations made on vertical motion by Mr. Knipping, and that given by the Barograph, with the observation upon horizontal motion as made by myself. This would give as the angle of emergence, both in Tokio and in Yokohama, something between 6° and 18°.

Depth of the Shock.

As the distance from Tokio and Yokohama to the surface point above the origin of the shock as measured on the map is in round numbers about 16 miles, and the angle of emergence is either 1.5° 6.25° 10.5° 11°, 18°, 31° or 45°. The depth of the shock as obtained by plotting may be either $\frac{3}{10}$, $1\frac{6}{10}$ $2\frac{8}{10}$ $3\frac{1}{5}$, $5\frac{1}{3}$ $9\frac{7}{10}$ or 16 miles.

However, as we have considered the second, third, fourth, and fifth of these angles of emergence to be the most probable, the most probable depths will be from $1\frac{1}{2}$ to 5 miles.

It must be remembered that even if we had sufficient data to make our results absolutely accurate, we should always expect to find that the origin would have different depths according to the point down to which we measured, the origin probably being something of the nature of an underground fissure which had definite lengths and breadths

and depths of its own. This calculation for the depth of the shock it will be observed depends on a certain vertical movement which was registered. *If this vertical motion is due to transverse vibrations the calculation is valueless.*

SOUND WHICH ACCOMPANIED THE SHOCK.

In Yokohama three correspondents seem to have heard a sound. Two of them, however, say that the sound they heard was during the shock and was such as might be due to the rattling of dishes, the straining of timbers &c. One observer, however, appears to have heard a sound before the shock which he likens to that which would be produced by a runaway waggon.

In Tokio one correspondent tells me that he heard a noise after the shock, whilst four tell me they heard a rumbling sound before it. One gentleman tells me that almost always before a shock he has heard a sound like that of a rushing wind beneath the earth, whilst another says the sound which preceded this shock was similar to that he has heard before other shocks—very like the sound of a heavy waggon. In one instance the sound is described as a distinct rumbling as if coming from a southerly direction. This was so distinct that he felt convinced that not only would there be an earthquake, but that it would be one of unusual severity. I myself did not hear any sound at or before the time of the shaking, nor have I ever heard a sound on other similar occasions. Many with whom I have conversed however have heard sounds.

At some places as at Kamiishi I find that a sound invariably precedes a shock, and sometimes precedes it so much that persons would have time to escape from a house before the arrival of the shock itself.

At this particular place, from what I know of its surroundings, it would seem that the sound must emanate from the ground itself, being produced by the earthquake at or near its origin.

In a large city like Tokio or Yokohama, however, that such should be the case is a supposition which is hardly necessary. The shock in reaching one extremity of the city

may, by the creaking it produces in the timbers of the houses and the rattling of loose shutters, and the like give rise to a roar, which, travelling through the air at the rate of 1000 feet per second, may reach the opposite side of the city before the shock, which latter coming through the soft alluvium probably does not travel at above 800 feet per second.

Some of the observations which we have point to an explanation like the latter, whilst others seem to point to the former; and it does not seem to be unlikely that there may be something of truth in both.

Rattling noises produced at the time of an earthquake seem to be characteristic of many Japanese houses.

This seems to arise from the sliding doors and windows which form the walls of almost every room in a Japanese house. One friend of mine who has had these sliding shutters fitted with glass tells me that they rattle *before* almost every earthquake, being sensitive to small tremors which without the noise would have been passed by unnoticed. This observation I can confirm by observations made in a brick building which has door-like windows. Each time that I have heard these gently rattle I have noted the same, and on several occasions they were subsequently proved to have been caused by an earthquake to the motion of which I myself had been insensible.

State of the Atmosphere, &c.

In all countries where earthquakes are felt and since the earliest times, connections have been sought between earthquakes and the state of the atmosphere. Considering that upon our globe there are, as Professor Heer tells us, at least two earthquakes in every twenty-four hours, it is impossible that there should be no coincidences of this description.

That fluctuations in the barometer, rainy seasons and meteorological changes generally, should be the immediate cause of earthquakes it is difficult to see the reason of. We can, however, imagine that these phenomenon may have a feeble and distinct relation to each other.

Thus it is possible to conceive how the sudden increase of barometric pressure, say to the extent of one inch over an area ready to give way may cause its sudden rupture or at least, be sufficient to produce a crackle in it.

Although there are many residents who will tell us that at the time of or before an earthquake peculiar sensations which might be due to atmospheric cause have been experienced, I am not aware that any definite connection between meteorological phenomena and the occurrence of earthquakes has hitherto been shown.

One resident in Tokio informs me that before an earthquake he often feels it close and dull. Before this last earthquake another tells me that he felt it oppressive. An observer in Yokohama says that before the shock the wind which had been blowing strongly from the south-west suddenly fell away to a calm. Immediately afterwards it blew freshly from an opposite direction, and it felt cold.

By looking over the records of the Yamato Yashiki Observatory I find the following.

At 9.30 p.m. on Feb. 20th the barometer stood at 29.92 from which point it gradually sank until the time of the shock when it was about 29.71. Shortly after this it commenced to rise, and at 9.30 a.m. next morning, that is on the 22nd, it reached 29.95.

The mean pressure for the whole month of Feb. was 30.134 inches.

On the	20th	it was	29.910
,,	21st	,,	29.845
,,	22nd	,,	29.913

But for several days before and after this date it was above 30 inches. We can therefore safely say that the shock took place whilst the barometer was low and at a time when the mercury in the tube had almost reached one of its lowest points during one of its falls.

Hitherto, in our reference to earthquakes being due to variations in atmospheric pressure we have only referred to them as being occasioned by an increase of such pressure In the case before us, an earthquake has occurred when the

reverse has taken place. We might here ask ourselves whether it is possible that changes of this description can in any way be connected with the occurrence of an earthquake. Is it possible, for instance, for gases which were safely held down when restrained by the earth's crust and a pressure equal to the weight of 30 inches of mercury to expand and crack the crust which bound them when a portion of this latter weight is removed? If it is, we have another agency to add to the list of causes which may tend to make an earthquake.

At 9.30 p.m. on the 21st that is about 3 hours before the shock the air temperature was 45.2° F. The average air temperature for the month at 9.30 p.m. is 41.1°. We can not say that there was anything remarkable in the temperature as observed either before or after the shock.

At 10 p.m. before the shock the wind was N.N.W. and had a velocity of 9.2 miles per hour at 3 a.m. Next morning it had shifted round to the E.N.E. and had a velocity of 10.2 miles per hour.

I might here record the dew points, the rain fall, the evaporation, the quantity of ozone observed in the atmosphere and the like which were recorded at and about the time of the earthquake, but as these phenomena do not seem to show any relation with it, and as it is an easy matter for those who are desirous of making such comparisons to obtain the necessary records I will omit to mention them.

Nausea and Sickness.

Amongst the accounts of large earthquakes we find many well authenticated records of the motion having been sufficiently great to produce a feeling of sickness and even vomiting. Mr. Mallet in his report to the British Association in 1858 mentions an instance where an earthquake produced nausea and vomiting amongst all the pupils of a large school.

From phenomena of this sort we do not appear to be exempt.

One correspondent writes that at the time of the shock he felt a slight nausea. A similar feeling was experienced by a gentleman who was staying in my house at the time.

Another writer says "I felt sea sick, but am a bad sailor; Another writes the sensation was like that of sea sickness, but there was more giddiness than actual nausea."

A near neighbour of mine says he felt quite sick. A resident in Yokohama repeats an experience of the same sensation.

One gentleman writing to me says it seemed "as if something awful and undescribable were going on which you were utterly powerless to avert. You felt small. The second sensation was one of sickness accompanied by giddiness and a violent head ache My wife has been seriously ill ever since."

Another correspondent says "a feeling of heaviness was felt before and at the time of the shock which passed away immediately afterwards." Whilst another says "his children were restless."

In two cases actual vomiting was produced. I have received three records of Japanese who slept through the shock and were not conscious of any thing whatsoever having taken place until next morning. To these I may add one foreigner.

These four instances are certainly remarkable as exceptional cases of sound sleep, an explanation for which I am unable to give.

If I had been able to collect information from all who felt the shock in and about Tokio and Yokohama no doubt, the records of sickness would have been more numerous. What the origin of this sickness may be, it is difficult to say. Perhaps it is in part due to the actual motion, like the sickness which is produced by the sea, and perhaps it is partly due to a sudden nervous excitement.

The lower animals so far as I have been able to learn do not seem to have been affected. This is perhaps, because at the time few observations were made upon them. One gentleman in Tokio tells me that at the time of the shock a cat which was in his room exhibited strong feelings of

distress, running backwards and forwards before the door which was closed, evidently wishing to escape. The foxes outside barked, and the horses kicked down some of the boards which confined them in the stable.

From these records there is no doubt but that the lower animals like their superiors were fully aware that something unusual was taking place from which they were evidently desirous to escape.

Conclusion.

Some of the more important general conclusions which I come to with regard to this earthquake and its effects are as follows. It originated somewhere on the eastern side of Yedo bay on or near to the coast of northern Kadzusa, at about 10 minutes before 1 on the morning of February 22nd, 1880. The origin was probably the formation of a fissure stretching about east and west parallel to the range of hills which divided Kadzusa and Awa and to many of the numerous faults which are seen to traverse the rocks of that district. It is possible that it may have been an attempt to form a new fissure or to prolong one which already existed, and thus prolong the line of volcanos coming through the Bonins and Oshima. From this origin the shock spread over an area of country within a radius of at least 120 geographical miles.

After passing some distance from the origin it seems to have spread with the greatest intensity towards the north-west and the north north-east.

The angle at which the wave emerged in Tokio and Yokohama was probably somewhere between 10° and 18° which would indicate that the shock originated at a depth of from between 3 and 5 miles. At Tokio the horizontal motion appears to me not to have been more than 10 millimeters, whilst its maximum velocity at the commencement of the shock was 21 mm. per second. In Yokohama the maximum velocity during the most severe portion of the shock was under two feet. The vertical motion may have been as much as 1 millimeter. The motion as evidenced by the senses and also by a diagram drawn by the motion of

the shock itself, shows that the movement was one of jolts rather than one of periodic vibration. Periodic vibrations, however, may have existed with the jolts. There were from 2 to 3 vibrations per second.

When we look at the records which I have given it is very striking to observe the dissimilarity in accounts which I have received respecting the same phenomena. With regard to the intensity of the shock, that it was manifested with different degrees in different localities is evidenced by its effect upon buildings, and this is confirmed by the sensations of observers. In looking at the records of direction we observe that the whole 32 points of the compass would not include the different directions which have been recorded by observers living in the same town, from which we infer that great errors might have been made by persons relying upon only one such observation. Although there were variations in direction for the same locality like Yokohama these variations were not so great as to include all the observations which were given to me. The evidence I rely upon when making this statement is the fact that such changes in direction were observed by instruments. Thus for instance in Tokio by 5 different instruments we had no less than 5 directions varying between N. and N.W. given to us. The reason that we obtained these different results is partly because the instruments were different in construction, but chiefly. I think on account of their being in different positions, one being on a hill, another in a valley, &c.

Not only did these instruments register different directions, but they also registered different intensities. We know from theoretical considerations and we have inferred from observations as in the present case, that a wave on passing from one rock to another suffers reflection and refraction. In this manner as it travels on from point to point it will change both in its direction and its intensity. Not only in this manner might the character of a wave be altered, but it may be affected by the contour of the ground. In a place like Yokohama partly situated on a plain, partly on the top of irregularly formed steep bluffs and partly in the

deep tortuous valleys which divide these bluffs these phenomena ought to be exhibited in a very remarkable degree.

The most severe earthquakes which visit Yokohama appear to come from the same quarter as the last great one, and the reflections and refractions which one wave suffers will be suffered in a similar manner by all the others. If we were to establish 20 simple but similar seismometers in different portions of the Yokohama bluff and settlement, I think that in a few months we should find that for certain shocks certain places had been in shadow whilst others had felt them severely, at one place the shock had passed in a westerly direction whilst in another it had passed in a north westerly direction.

In fact we should be able to map a shock and show it ramifying across a plan of Yokohama like the branches of a tree, the thickness of which at different points might be used to denote its intensity. By experiments of this sort we should test the value of our ground, as being favourable or unfavourable for the display of seismic energy. We should in fact put ourselves in the same position with regard to the hill or plain on which we live, as we do with regard to the water which we drink. We analyze our wells, why not analyze the stability of our land? This last earthquake has shown us that earthquake phenomena are exhibited differently on different properties although they may be adjacent, and it now remains for us to find out and measure the nature of these differences. Through the kindness of Mr. W. H. Talbot, and Mr. T. Rose two similar instruments have been established in Yokohama, one upon the bluff and one in the settlement and it is hoped that very shortly we shall obtain some valuable results from them. These however will only give the different intensities and directions at two points for any given shock, whilst to construct a map it is necessary that machines should be established at a number of localities. The problem to be worked out is so far as I am aware one which has not hitherto been attempted. It is one which we have the opportunities to work at, and further it would be of the greatest interest not only as a tribute to scientific progress, but it would also

be of interest to every one who lives upon the shaken area. All things considered the solution of this problem is to be strongly recommended to the inhabitants both of Tokio and Yokohama. I am glad to state that very shortly ten similar seismometers will be established in Tokio.

Similarly we might test our buildings and find out the effects of different foundations in warding off shocks.

When we look over the records of earthquakes which have been felt during the last few months say between October, 1879 and the middle of April, 1880, and observe that in this period we have experienced no less than 50 distinct shakings two of which were sufficiently strong to destroy our chimneys, we see that we are passing through a period of unusually severe seismic activity. If the instruments with which these records were made had been placed in Yokohama instead of Tokio, I think it more than probable that the number of observations would have been greater. A similar period of great activity seems to have occurred in the spring of 1873 and people became alarmed lest these smaller shakings should be the warnings of something more severe which was to follow.

Prof. Heer tells us that on an average in the world there are about 2 earthquakes every 24 hours. Lately in Japan we have had as many as 5 distinct shocks in one night, and I think that if we had the means of collecting records from the various portions of Japan Professor Heer's average might be furnished without an appeal to any other country than Japan itself.

If we turn to the records of other countries and see that during the past year earthquakes have been unusually frequent even in places which seldom if ever experience shocks, many would be inclined to think that the ultimate cause of these shocks had been identical. During the early part of 1879 shocks were felt in many parts of Great Britain. Switzerland, Italy, Hungary and Sicily were also violently shaken. The year was concluded with a series of severe shocks which burst open doors, knocked down various articles from shelves and tables at and near Geneva on the night of

Dec. 30th. What these general coincidences which exist between the occurrence of the seismic period of Japan and that of parts of Europe may mean I can not say, but I should be inclined to regard it as being simply accidental.

Many in Japan have no doubt speculated as to whether the shock which has now gone by was the climax of the period through which we are passing, or whether the climax is yet to come. One way in which we might examine such a question would be by comparing these shocks with those which have passed. Thus in 1854 there was a severe shock which shock was followed by another in 1855. Similarly we have had a tolerably severe shock in December, 1879 followed by another in February, 1880. If we had established the fact that in the occurrence of earthquakes there was such a thing as periodicity, then although the two shocks are much smaller than those which occurred 25 years ago we might look upon them as being their representatives and we should now be in the position of looking forward to a period of rest.

However as the law of periodicity has not been established, if we reflect upon the various causes which may produce an earthquake and the dissimilarity and variability of the materials on which these causes act, it is difficult to see how we can hope to establish a law for earthquakes like that about which we have just now spoken.

Another method which we might follow when speculating on the probability of farther shakings being in store for us would be to consider whether in consequence of the shaking we have already had, the seismic energy of the districts around Tokio and Yokohama is exhausting itself or not.

If we turn to the records of earthquake-shaken countries we shall see that nearly every seismic area appears to have its periods of activity.

We have now been experiencing at least two months of such a period, during which time we have had two tolerably severe shocks. All this seems to mean that the ground is being elevated or depressed, or that volcanic forces are endeavouring to form a vent. After all the motion which has

taken place we can imagine that the ground has in every probability been gradually assuming a more stable condition and that the volcanic forces have been gradually losing energy. Whether the ground has so far settled that for a while it will remain at rest, or whether underground energy has sufficiently expended itself is a matter of the purest speculation.

One thing however appears certain and that is, that having already passed through so much of a seismic period the chances of a repetition of a destructive shock become daily less and less.

I will now conclude. What I have endeavoured to do has been to give the history of an earthquake from the sudden jar which gave it birth, to the time it passed our dwellings to fill us with alarm, until finally spreading outwards in ever widening circles its energy and motion became dissipated and it died. Although its life was ephemeral perhaps not existing as an earthquake for more than 10 minutes its energy was sufficient to shake the largest mountains. What I have said about it has not been founded so much upon my own observation as upon the observation of others In places my deductions from these observations have I think been quite legitimate but in other places my remarks may be only speculation.

If this earthquake had taken place in other countries where instead of a single town like Yokohama acting as one great seismograph there had been many cities to act in that capacity the results which would have been obtained would no doubt have been more accurate and more numerous. Here the materials have been small and as a consequence all I fear is that whilst endeavouring to extract from them all it was possible for them to yield, they may perhaps have been here and there strained too far and as a result readers may think that conclusions have now and then been based on very meagre data. Should this be so the only excuse I can offer is that opportunities like these coming so seldom we ought to use them to their best advantage for it is only by a study of those forces which shake our globe that we can obtain a true knowledge

of many of the great changes which have brought it to the condition in which it now exists.

Further we must study earthquakes in order to glean all we can about their effects, so that we may in future guard ourselves against the calamities they occasion.

From the lessons we have learnt by this last earthquake it is possible by slight variations in the structure of our houses to prevent similar destruction under like circumstances taking place in future.

Only a few years ago earthquakes and like phenomena which were ill understood, were regarded as curses on the country where they happened, and became, in consequence, a fruitful source of superstition. Even to this day we find that catastrophes of this description have in South America their anniversaries which are solemnly commemorated.

Now, however, since the labours of men like Mallet, we regard them as a feature in the general scheme of nature's operations which are capable of investigation, and it is my sincere hope that in the preceding pages, I may at least have added a mite towards the elucidation of some of the phenomena attending the manifestation of one of the smaller numbers of a series, which we know from history to have been both long and terrible.